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# Investigating the Influential Factors on the Welding Performance of F91 Steel Valve Bodies Utilizing Submerged Arc Welding

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***Abstract:*** *F91 steel, a high-performance alloy, is prevalently utilized in fabricating valve bodies for operations in elevated temperature and pressure environments. Submerged arc welding (SAW), acclaimed for its efficiency and superior quality outputs, is predominantly employed in welding F91 steel. Nevertheless, the welding efficacy of F91 steel is subject to various influencing factors. This manuscript delineates an experimental investigation into the principal factors affecting the welding performance of F91 steel utilizing SAW, encompassing welding process parameters, welding materials, preheating, post-weld heat treatment procedures, and the environmental conditions during welding. Through a comprehensive analysis of these elements, this research offers insightful guidelines and reference points for enhancing production practices, thereby augmenting the quality and reliability of welding in F91 steel valve bodies.*

***Keywords:*** *F91 steel, Submerged arc welding (SAW), Welding performance, Experimental investigation*

## 1. Introduction

F91 steel, distinguished by its high alloy content, exhibits exceptional resistance to high temperatures and corrosion and showcases robust strength. These attributes render it exceedingly suitable for application in manufacturing high-temperature and high-pressure equipment across various industries, including power generation and petrochemicals, particularly in constructing valve bodies and pipelines. Welding represents a critical fabrication approach for F91 steel components, significantly influencing their performance and longevity. Owing to its efficiency and elevated quality of results, automatic submerged arc welding is a widely adopted methodology for the welding of F91 steel. However, the process is not devoid of challenges, as multiple variables can impact the welding performance[1-4]. Ensuring welding quality through meticulous scientific analysis and judicious process management is imperative.

## 2. Welding Process Parameters

### *2.1 Welding Current and Voltage*

With the research, Wang, R., & Liu, G.[5] claimed the welding current and voltage considerably affect a weld's quality[5]. An further investigative experiment was conducted to ascertain the influence of these parameters on weld quality with the following setup:

### *2.1.1 Experimental Methodology*

1) Plates of F91 steel measuring 300 mm x 150 mm x 12 mm were employed.

2) Welding currents were adjusted to 400 A, 450 A, and 500 A.

3) Welding voltages were set to 30 V, 32 V, and 34 V, respectively.

4) The welding speed was consistently maintained at 300 mm/min.

### *2.1.2 Experimental Results*

1) Utilizing a welding current of 400 A and a voltage of 30 V resulted in insufficient weld penetration and notable fusion deficits.

2) An increment to 450 A for the welding current and 32 V for the voltage achieved optimal metal fusion and weld quality.

3) Further increments to 500 A and 34 V caused burn-through, roughness in the weld metal, and decreased mechanical properties.

#### *2.1.3 Experimental Conclusion*

Optimal weld quality is achievable through an appropriate amalgamation of welding current and voltage, specifically at 450 A and 32 V, facilitating adequate metal fusion, uniform weld structure, and, thereby, an enhancement in weld quality.

### *2.2 Welding Speed*

According to Chen, H., & Wu, Q.(2021)[6], the speed of welding significantly influences weld morphology and the resulting microstructure line with this， an experimental assessment was conducted to elucidate the impact of welding speed on weld quality, entailing the following experimental setup:

#### *2.2.1 Experimental Methodology*

1) F91 steel plates with dimensions of 300 mm × 150 mm × 12 mm were utilized.

2) The welding current and voltage were consistently set at 450 A and 32 V, respectively.

3) Welding speeds were adjusted to 200 mm/min, 300 mm/min, and 400 mm/min.

#### *2.2.2 Experimental Results*

1) At a 200 mm/min welding speed, pronounced weld penetration and a broad heat-affected zone with a coarse microstructure were observed.

2) Elevating the welding speed to 300 mm/min yielded moderate weld penetration, a narrower heat-affected zone, and a refined microstructural composition.

3) Further increasing the welding speed to 400 mm/min compromised weld penetration and elevated the incidence of fusion lapses.

#### *2.2.3 Experimental Conclusion*

A welding speed that maintains a judicious control over welding heat input, such as 300 mm/min, contributes favorably towards optimal weld morphology and microstructural characteristics, subsequently boosting the mechanical properties of the weld.

## 3. Welding Materials

### *3.1 Selection of Welding Wire and Flux*

The selection of appropriate welding wire and flux is imperative for the resulting composition and performance of the weld metal[7-8]. This study aims to elucidate the influences exerted by various combinations of wire and flux on the weld quality through systematic experimentation.

#### *3.1.1 Experimental Methodology*

1) For the experiments, plates of F91 steel with dimensions of 300 mm x 150 mm x 12 mm were utilized.

2) The welding wire selected was AWS A5.28 ER90S-B9, which is compatible with F91 steel.

3) Four fluxes were chosen for evaluation: F7A2-EM12K, F7P2-EM12K, and F9A4-EB2.

#### *3.1.2 Experimental Results*

1) The application of F7A2-EM12K flux was observed to diminish the purity of the weld metal and impair its mechanical properties.

2) Conversely, using F7P2-EM12K flux yielded weld metal of moderate purity and satisfactory mechanical properties.

3) The utilization of F9A4-EB2 flux resulted in the superior purity of the weld metal and the most

favorable mechanical properties.

#### *3.1.3 Experimental Conclusion*

The findings substantiate that the employment of a welding wire with a composition congruent to the base material, paired with high-purity flux (e.g., F9A4-EB2), considerably enhances the purity and mechanical properties of the weld metal, thus guaranteeing elevated welding quality.

### *3.2 Storage and Handling of Welding Materials*

Previous research has established that the welding quality can be significantly influenced by the manner of storage and handling of the welding materials, according to Lin, F., & Zhao, H.[9]. An experimental analysis investigated the impact of different storage and handling conditions on weld quality.

#### *3.2.1 Experimental Methodology*

1) Same as before, F91 steel plates with dimensions of 300 mm x 150 mm x 12 mm were selected.

2) Welding wires were allocated to three storage conditions: room temperature, dry storage, and a humid environment.

3) Fluxes were stored under two conditions: room temperature and dry storage.

#### *3.2.2 Experimental Results*

1) Welding wires and fluxes kept at room temperature exhibited satisfactory performance, thus yielding good weld quality.

2) Those stored in dry conditions demonstrated exemplary performance and produced the optimal weld quality.

3) Conversely, materials stored in a humid environment encountered issues such as porosity and cracking during welding, culminating in subpar weld quality.

#### *3.2.3 Experimental Conclusion*

The experimental outcomes advocate for the necessity of storing welding materials in a dry, uncontaminated environment and subjecting them to requisite pre-treatment processes (e.g., drying and cleaning) before usage. This eliminates moisture and impurities, thereby assuring a high standard of welding quality.

## 4. Preheating and Post-Weld Heat Treatment

### *4.1 Preheating treatment*

Data from studies conducted by Akhtar, M.[10] in 2017 suggested that preheating is a significant preventative measure against weld cracking. Through a structured experimental approach, this investigation sought to elucidate the relationship between preheating temperatures and their effect on the propensity for welding cracks.

#### *4.1.1 Experimental Methodology*

1) Material Selection: Plates of F91 steel with dimensions of 300 mm x 150 mm x 12 mm were employed for the study.

2) Temperature Variants: Preheating temperatures were methodically set at 100°C, 200°C, and 300°C.

3) Welding Parameters: The experiments were standardized by setting the welding current at 450 A, the welding voltage at 32 V, and the welding speed at 300 mm/min.

#### *4.1.2 Experimental Results*

1) When preheated at 100°C, the rapid cooling of the weld metal was observed, which presented a pronounced inclination towards cracking.

2) Preheating at 200°C enabled moderated cooling of the weld metal, notably diminishing the cracking tendency.

3) The optimal condition was obtained at a preheating temperature of 300°C, where the cooling rate of the weld metal was ideal, markedly minimizing cracking tendency and enhancing weld quality.

#### *4.1.3 Experimental Conclusion*

It is conclusively established that a judicious selection of preheating temperatures, within the range of 200°C to 300°C, is imperative for reducing weld cracking occurrences and enhancing overall weld integrity. Henceforth, The appropriate preheating temperature must be guided by the specifics of the welding process and the material characteristics involved.

### *4.2 Post-Weld Heat Treatment*

Post-weld heat treatment emerges as a pivotal technique to augment weld performance[11]. This section delineates an empirical investigation to discern the differential impacts of various post-weld heat treatment methodologies on weld performance.

#### *4.2.1 Experimental Methodology*

1) Material Selection: F91 steel plates with the exact dimensions, as previously mentioned, were utilized for this experiment.

2) Heat Treatment Regimes: Two distinct post-weld heat treatments were administered: tempering and annealing.

3) Thermal Parameters: The tempering process was conducted at 700°C for 2 hours, while the annealing process was held at 750°C for 2 hours.

#### *4.2.2 Experimental Results*

1) Welds without heat treatment exhibited profound residual stresses, a proliferation of brittle phases, and compromised mechanical properties.

2) The application of tempering to the welds significantly ameliorated residual stresses, resulted in a refined microstructure and markedly enhanced the mechanical properties.

3) The annealing process essentially nullified residual stresses, yielded a uniformly refined microstructure and showcased superior mechanical characteristics compared to the tempered welds.

#### *4.2.3 Experimental Conclusion*

Post-weld heat treatments, particularly tempering and annealing, are conclusively proven to substantially elevate weld mechanical properties, obliterate residual stress, and ameliorate the weld microstructure. According to the empirical evidence, the annealing treatment exhibits superiority over tempering. However, the optimal selection of a post-weld heat treatment strategy should be intricately aligned with the specific production requisites and conditions.

## 5. Welding Environment

### *5.1 Environmental Temperature and Humidity*

The welding environment's temperature and humidity significantly influence the welding process and weld quality. The following experiments were conducted to investigate the impact on weld quality:

#### *5.1.1 Experimental Methodology*

1) F91 steel plates measuring 300 mm × 150 mm×12 mm were used.

2) Welding environment temperatures were set at 10°C, 20°C, and 30°C.

3) Relative humidity levels were set at 40%, 60%, and 80%.

4) Welding current was set at 450 A, welding voltage at 32 V, and welding speed at 300 mm/min.

#### *5.1.2 Experimental Results*

1) The weld metal cooled rapidly at 10°C and 40% relative humidity, leading to high residual stress and poor weld quality.

2) The welding process was stable at 20°C and 60% relative humidity, resulting in good weld quality.

3) At 30°C and 80% relative humidity, the welding process was unstable due to high moisture content, resulting in weld porosity and poor quality.

#### *5.1.3 Experimental Conclusion*

Moderate environmental temperature and humidity (e.g., 20°C and 60%) benefit welding, while extreme temperatures and high humidity can adversely affect weld quality. Ensuring suitable welding environment conditions is critical for maintaining welding quality.

### *5.2 Environmental Cleanliness*

The cleanliness of the welding environment also impacts weld quality. The following experiments were conducted to explore the impact of different cleanliness levels on weld quality:

#### *5.2.1 Experimental Methodology*

1) F91 steel plates measuring 300 mm x 150 mm x 12 mm were used.

2) Welding environments with varying cleanliness levels were employed: clean, dusty, and oily.

3) Welding current was set at 450 A, welding voltage at 32 V, and welding speed at 300 mm/min.

#### *5.2.2 Experimental Results*

1) The welding process was stable in a clean environment, producing good weld quality.

2) In a dusty environment, the welding process was unstable, leading to slag inclusions and poor weld quality.

3) The welding process was unstable in an oily environment, producing poor weld porosity and quality.

#### *5.2.3 Experimental Conclusion*

Maintaining a clean welding environment is crucial for ensuring weld quality. Dust and oil contamination can adversely affect the welding process and weld quality. Therefore, cleaning the welding environment and workpieces before welding is necessary.

## 6. Conclusion

In summary, the welding performance of F91 steel valve bodies using automatic submerged arc welding is influenced by multiple factors. Welding quality can be effectively controlled and improved by carefully considering welding process parameters, welding materials, preheating and post-weld heat treatment, and the welding environment. The findings of this study offer valuable insights into the actual production process, aiding in the optimization of welding technology and enhancing the reliability and service life of F91 steel valve bodies. Future research could further delve into optimizing welding parameters and developing new welding materials to achieve superior welding performance of F91 steel.

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