Development of Standard Welding Procedure Specification for Nuclear Power Plant

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1. Introduction

In case of conventional Welding Procedure Specification (WPS) and Procedure Qualification Record (PQR) system of American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (BPVC) and Korea Electric Power Industry Code (KEPIC), each manufacturer shall perform discrete welding qualification test and any use of the WPS developed by other manufacturer is prohibited.[1, 2]

As a result, a lot of WPSs and PQRs which contained nearly identical technical contents such as materials and welding methods have been developed repeatedly. Those have invoked a lot of efforts such as economic cost and time.

Standard Welding Procedure Specification (SWPS) which developed by designated responsible organizations is the welding procedure specification which can be used for production weld without any specific procedure qualification test performed by manufacturers. American Welding Society (AWS) and Welding Research Council (WRC) had began to develop the SWPSs in the beginning of 1980s[3] and then 33 SWPSs are adopted by ASME BPVC Section IX.[1]

For the use of these SWPSs in nuclear power plant construction, SWPS shall satisfy the Owner's requirements and regulatory requirements as well as the construction Codes (ASME BPVC Sec. III or KEPIC-MN).

However, SWPS developed by AWS does not satisfy these requirements such as fracture toughness requirements of ferritic steel, intergranular corrosion test and heat input limitation of stainless steel, etc. Consequently, most of SWPSs in AWS allowed by ASME and KEPIC were not possible to use directly in the field of nuclear power plant.

Therefore, development of SWPSs for nuclear power plant which satisfy all of the related requirements are required to improve reliability of the welding processes of manufacturing, construction, repair and replacement.

2. Methods and Results

2.1 Analysis of Conventional WPSs Applied to Nuclear Power Plants in Korea

The conventional WPSs already used in nuclear industry were investigated for the development of new SWPS in KEPIC. The scope was mainly focused on WPSs applied to pipe welding in nuclear power industries such as manufacturer, installer and repair/replacement organization in Korea.

In nuclear power plants, base metals mostly consist of P-No.1, P-No.3, P-No.5A and P-No.8 materials. Only a few WPSs were developed by several manufactures for P-No.3 and 5A materials. Therefore, the WPSs of P-No.1 (carbon steel) and P-No.8 (stainless steel) as widely used common materials, whose weldability has been approved for a long time, were reviewed in this study.

It was discovered that welding processes were limited to GTAW, SMAW and FCAW in 490 kinds of WPSs.

Table 1 and 2 list the analysis results of WPSs for carbon steel and stainless steel respectively showing that the welding variables and qualification test conditions in most WPSs and PQRs used in electrical power industries in Korea were nearly identical and there is not a greatly clear difference between manufactures. As expected, it is considered that actually many manufacturers have used similar WPSs with similar welding variables and tests even if the WPSs were developed differently by each manufacturers.

Table 1. Analysis result of conventional WPSs for carbon steel

Material	P-No.1 (Carbon steel)		
Welding Process	GTAW	FCAW	SMAW
Preheat Temp. (℃)	Less 19mm T*: 10 / Over 19mm T: 93~120		
Interpass Temp. (℃)	Maximum 250~300		
Backing gas	N/A		
Ampere range (A)	80~200	160~300	70~200
Voltage range (V)	10~16	10~16	22~30
Speed (CPM)	6~15	10~50	8~15
Shielding gas (ℓ/min)	Ar / 8~15	CO_2 / 20~25	N/A

*T: Thickness of base metal

Table 2. Analysis result of conventional WPSs for austenitic stainless steel

Material	P-No.8 (Austenitic stainless steel)		
Welding Process	GTAW	FCAW	SMAW
Preheat Temp. (℃)	Minimum 10		
Interpass Temp. (℃)	Maximum 176		
Backing gas	Ar (99.99 %)		
Ampere range (A)	120~300	120~300	60~120
Voltage range (V)	11~19	11~19	20~30
Speed (CPM)	12~45	12~45	6~12
Shielding gas (ℓ/min)	Ar / 8~15	CO_2 / 20~25	N/A

2.2 Review of Technical Requirements for nuclear Power Plants in Korea

For the determination of SWPS's suitability and classification of welding variables and additional requirements necessary for the development of SWPS in KEPIC, various technical requirements such as Construction Codes, Design Specifications, Safety Analysis Report (SAR) and Regulatory Guide for construction of components and pipings of nuclear power plants in Korea were reviewed.

Table 3 shows the review result of technical requirements of nuclear power plants in Korea.

Table 3. Technical requirements of nuclear power plants in Korea

General limitations	- GTAW shall be used for the root pass of all circumferential butt welds, accessible from one side only. - More than 2 layers shall be required. - In case of fit-up of socket welding, the gap distance shall be limited to the range of 1.6~3.2 mm.
Welding materials	- For SMAW, low hydrogen type electrode shall be used. - 309 or 309L electrode shall be used for dissimilar metal welding. - Maximum bead width should not exceed that of 6 times the core diameter of filler metal for carbon steel (stainless steel: 4 times ~).
Heat treatments	- The minimum preheat temperature is 10 ℃(50 ˚F). - Maximum PWHT temperature shall not exceed the specified minimum temperature by more than 83℃ (150˚F).
Austenitic stainless steel	- Mainly focused on the prevention of sensitization and control of heat input. - IGC tests shall be performed in accordance with ASTM A262 Practice A or E when the carbon content of material exceeds 0.03 %. - For GTAW process, the allowed maximum heat input and maximum bead width shall be limited to 60 kJ/in. and less than 4 times the core diameter of filler metal respectively. - Maximum carbon content and interpass temperature should be limited to 0.065 % and 170 ℃ respectively. - The weld materials with 5~20 FN (Ferrite No.) should be used in order to prevent from hot cracking.
Fracture toughness requirement	- ASME BPVC Section III and KEPIC-MN require impact tests for the thickness exceeding 5/8 inch (16mm) of ferritic steels.

2.3 Technical Deviations of SWPSs in AWS

To adopt the SWPSs developed by AWS in nuclear power plants in Korea, the selected SWPS shall satisfy technical requirements referred in 2.2.

However, there are some deviations between SWPS and technical requirements. Table 4 shows some technical deviations of SWPS in AWS with technical requirements in nuclear power plants in Korea.

Consequently, most of SWPSs in AWS allowed by ASME and KEPIC were not possible to use directly in the field of nuclear power plant.

Table 4. Technical deviations of SWPS in AWS

Unsatisfaction of the construction Code requirements	- SWPS cannot be used for the thickness exceeding 5/8 in. (16 mm) of ferritic steels by fracture toughness requirements of construction Code.
Discrepancy between technical requirements in plant specifications and SWPS	- IGC test requirements in austenitic stainless steel: there is no SWPS for P-No.8 material qualified with IGC Test. - Heat input control of sensitization: welding voltage, amperes, speeds and etc. were not specified in SWPSs. - Much of SWPSs were developed with non-low hydrogen type welding materials such as E6010. - Maximum bead width, ferrite No., minimum preheat temperature requirement, and etc. were not specified in SWPSs

2.4 Development of New SWPSs for Nuclear Power Plants in Korea

Fourteen (14) draft SWPSs were developed using autonomously conducted procedure qualification tests and PQRs donated from nuclear industry. Procedure qualification tests were conducted at both minimum and maximum heat inputs for each thickness of base metals. Donated PQRs were used for extension of variables such as welding current, voltage, speed, filler metal size, interpass temperature, tungsten electrode size for GTAW, and etc.

Table 5 shows the scheme for the development of new SWPSs

Table 5. Scheme for the development of new SWPSs

SWPS No.	Material	Welding method	Qualified T range (mm)	Other tests
SWPS-0101-GT-01	P-1 to P-1	GTAW	1.5 ~ 16	-
SWPS-0101-GT-02			16 ~ 36.6	Charpy impact test*
SWPS-0101-SM-01		SMAW	1.5 ~ 16	-
SWPS-0101-SM-02			16 ~ 36.6	Charpy impact test
SWPS-0101-GF-01		GTAW+ FCAW	1.5 ~ 16	-
SWPS-0101-GF-02			16 ~ 36.6	Charpy impact test
SWPS-0101-GS-01		GTAW+ SMAW	1.5 ~ 16	-
SWPS-0101-GS-02			16 ~ 36.6	Charpy impact test
SWPS-0808-GT-01	P-8 to P-8	GTAW	1.5 ~ 10	IGC test
SWPS-0808-GT-02			5 ~ 55	IGC test
SWPS-0808-SM-01		SMAW	1.5 ~ 10	IGC test
SWPS-0808-SM-02			5 ~ 55	IGC test
SWPS-0808-GS-01		GTAW+ SMAW	1.5 ~ 10	IGC test
SWPS-0808-GS-02			5 ~ 55	IGC test

*Charpy impact test temperature : 0℃

3. Conclusions

With the demand for development of new SWPS which can be used in nuclear power plants in Korea, several draft SWPSs were developed. The developed draft SWPSs and supporting data (autonomously conducted procedure qualification test results, donated PQRs, additional test results, etc.) are under review by a KEPIC committee in charge of KEPIC welding requirements. From the use of developed SWPS, a lot of economic effects by reducing the overall cost of qualifying welding procedures in whole electrical power industries are expected. Also, the new SWPS in KEPIC can improve the reliability of the welding processes of manufacturing, construction, repair and replacement industries.

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