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Report on fabrication of the pin components for irradiation of FUJI project (Collaboration in the research and development of advanced sphere-pac fuel among PSI, JNC, and NRG)

(Technical Document)

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Report on fabrication of the pin components for the irradiation test in the FUJI project (Collaboration in the research and development of advanced sphere-pac fuel among PSI, JNC, and NRG)

(Technical Document)

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Abstract

Japan Nuclear Cycle Development Institute (JNC) has conducted the collaboration concerning vibro-packed fuels with Paul Scherrer Institut (PSI) in Switzerland and Nuclear Research & consultancy Group (NRG) in the Netherlands. The project "Research and Development of Advanced Sphere-pac Fuel" is called FUJI (**FU**el irradiations for **J**NC and PS**I**) Project. In this project, three types of fuels that are sphere-pac fuels, vipac fuels, and pelletized fuels will be irradiated in the High Flux Reactor (HFR) to compare the fuel performance.

Based on the drawing which has been agreed among three parties, fabrication of the pin components and welding of the upper and lower connection endplugs were performed in accordance with ISO9001 in JNC. This report describes data of fabricated pin components, results of welding qualification tests, and quality assurance of the welded components.

The fabrication of pin components was successfully completed and they were delivered to PSI in October 2002.

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FUJI プロジェクトにおける照射試験用燃料部材の製造報告

（研究報告）

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要旨

核燃料サイクル開発機構（JNC）では、振動充填燃料に関する共同研究「Research and Development of Advanced Sphere-pac Fuel（通称 FUJI (**Fu**el irradiations for **J**NC and PS**I**)プロジェクト」を、スイスの Paul Scherrer Institut (PSI)及びオランダの Nuclear Research & consultancy Group (NRG)との間で実施している。本プロジェクトでは PSI で製造したスフェアパック、ペレット及びバイパックの 3 タイプの燃料を、オランダ Petten にある High Flux Reactor (HFR)で比較照射する計画である。

JNC は照射試験用燃料のピン部材を製造する役割を担っており、三者間で合意された製作図面に従って部材の製作及び接続端栓の被覆管への溶接を実施した。この報告書は照射用部材の製造結果、また接続端栓の溶接に関する施工試験及び溶接された部材の品質保証に関するものである。

製造は無事完了し、製造された部材は 2002 年 10 月に PSI に送付された。

[1] 環境保全・研究開発センター　先進リサイクル研究開発部
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Based on the drawing [1] which has been agreed among three parties, fabrication of the pin components and welding of the upper and lower connection endplugs were performed. This report describes data of the fabricated pin components, results of welding qualification tests, and quality assurance of the welded components.

All components were delivered to PSI after the fabrication, the welding and the inspection were completed. All operational works were performed in accordance with ISO 9001 in JNC.

2. Fabrication of pin components for irradiation

2.1. Item of parts and material for pin components

The pin components consist of several parts, such as cladding tubes, endplugs, and parts for inside of the claddings. The pin is composed of upper and lower segments to be connected with the connection endplugs welded with the cladding tubes. Table 1 shows the list of the component parts and materials. The number of the components delivered to PSI is shown in Table 2.

2.2. Characteristics of material for pin components

The pin components were made of 20% cold worked advanced austenitic stainless steel (PNC1520). The composition of the PNC1520 is shown in Table 3. Long tubes for the cladding tube and bar materials for other parts were used as raw material. The plenum springs were made of SUS304WPB and the fuel seal discs were made of tungsten whose purity is specified as 99.95 %. The fuel seal discs will be used in the sphere-pac and vipac fuel segments to prevent the finest insulator fragments going into a gap between the cladding and the connection endplug, and especially in vipac fuel segments, to prevent the intermixing taking place at the boundary between insulator spheres and vipac fuel fragments.

2.3. Fabrication of the pin components

The pin components were fabricated by machining from bar materials of PNC1520. Since the PNC1520 is cold worked, the cutting should be performed carefully to prevent distortion. The fuel seal discs were fabricated by pressing plate materials with the die that was peculiar to this work in order to satisfy the specified dimension.

2.4. Inspection of the pin components

The fabricated pin components were inspected with similar procedure to JOYO and MONJU in accordance with ISO9001. The inspection criteria and methods are described in Table 4. Visual and dimensional inspections were performed for all pieces of the product. A standard certificated gauge was used for the dimensional inspection.

2.5. Fabrication results

The inspection results of fabricated pin components are shown in Table 5-Table 16. The results of visual, dimensional, and bowing inspections show all pieces of the components satisfy the specifications without any failures.

3. Welding of connection endplug

The upper and lower connection endplugs were supposed to be beforehand welded with the cladding tubes in JNC before the delivery to PSI. The welding procedure in JNC for the FUJI project consisted of welding qualification test, welding and inspection for delivery. The welding conditions were decided through the welding qualification test. The welding for delivery was performed under the same conditions. The welding integrity was examined in visual inspection, X-ray radiography, and He-leak test.

3.1. Welding qualification test

3.1.1. Test procedure and conditions

The welding qualification test was performed from 12th to 25th of July 2002.Fig. 1 shows the process of the welding qualification test. First, the ID number of the cladding and the connection endplug was checked and the connection endplug was joined to the cladding. After the welding, non-destructive (visual inspection and X-ray radiography) and destructive examination (burst test, tensile test and metallographic inspection) were performed to check the integrity of the welded specimen. The welding conditions are shown in Table 17 and the current chart is shown in Fig. 2.

The welding machine for the welding of MONJU and JOYO pins was used for this welding work and it was operated by the personnel qualified in accordance with ISO 9001.

3.1.2. Welding specimen and ID number

The dimension of the welding specimens for the qualification test and their ID number. are shown in Table 18 and Table 19. Since the upper connection endplug has a shorter distance from the welding joint to the flat surface, only the welding of the upper connection endplug to the cladding was performed in the qualification test. The length of cladding in this test was 100 mm, which was shorter than the actual cladding length of 400 mm, because the difference of the cladding length does not have any effect on the result of the welding.

3.1.3. Non-destructive examination

Visual inspection, dimensional measurement, and X-ray radiography were performed in the non-destructive examination. Table 20 shows the inspection method and the criterion. In order to qualify the welding procedure, there should not be any specimen which is out of the criterion.

3.1.4. Destructive examination

Burst test, tensile test, and metallography were performed in the destructive examination. Table 21 shows the inspection method and criterion.

The burst test was performed to examine the strength of the welded specimens against the internal pressure. The testing device is composed of the pressure tank, the pressurizing pump, the controller, and the chart recorder. A specimen is pressurized by injected water from the testing device. The maximum pressure of this device is 191.6 MPa.

The experiment procedure was as following.

(1) The specimen was cut into about 50 mm in length.
(2) The open end of the specimen was connected to the water injection pipe.
(3) Pressurized water (150 MPa) was injected to the specimen at a rate of 17.5 MPa/min.
(4) The specimen burst when the inner pressure exceeded its ultimate strength. The pressure was recorded as the burst pressure.

The burst pressure should be higher than 74 MPa. This value is referred from the specification for MONJU pins, which is worse conservation for this work.

Tensile test was performed to examine the ultimate tensile strength of the welded specimens. A specimen was pulled at constant velocity until it would be broken.

The experiment procedure was as following.

(1) The specimen was cut into about 50 mm in length.
(2) The specimen was fixed at the upper and lower parts with the clamps and pulled at 2.5 mm/min.
(3) The specimen was broken when the applied tensile force exceeded the ultimate tensile strength of the specimen. The tensile force at which the specimen was broken was recorded as the tensile strength.

The tensile strength should be higher than 4903 N. This is referred from the specification for MONJU pins, which is worse conservation for this work.

In order to qualify the welding procedure, there should not be any specimen which is out of the criterion.

3.1.5. Result of non-destructive examination

Table 22 shows the result of non-destructive examination. The results show all specimens satisfy the criterion without any failure.

3.1.6. Result of destructive examination

Table 23 shows the result of destructive examination. The metallographic images are shown in Fig. 3. The results show all specimens satisfy the criterion without any failure.

Consequently, since all welded specimens in this work satisfied the specifications, the welding condition was qualified.

3.2. Welding of the connection endplug for delivery

3.2.1. Welding work

Welding of the connection endplug was performed under the same conditions as the qualification test.

Non-destructive examination (visual, dimensional, X-ray radiography, and He-leak inspection) was performed for all welded components.

3.2.2. Non-destructive examination

Visual and X-ray radiograph inspections were performed by the same method as the qualification test (shown in Table 20).

Additionally, He-leak inspection was performed to evaluate the integrity of the welded joint. The inspection employed vacuum hood method which follows the JIS (Japan Industrial Standards) Z2330, Z2331. The inspection method was as follows.

(1) The inside of the welded component was evacuated and the welded joints was covered with a hood.
(2) The inside of the hood was filled with He gas and the He content in the evacuated air was measured by a He detector.

The detector was normalized in advance of the inspection and the background He content was measured for each sample.

The measurement was carefully conducted to avoid scratching claddings and connection endplugs. The maximum of He leakage was specified as 3.0×10^{-9} Pa m^3/s and the accuracy of the detector was better than 1.0×10^{-11} Pa m^3/s.

Finally, the upper and lower segments were connected and the overall bowing after connecting was measured to assure the straightness of the assembled pins.

3.2.3. Result of non-destructive examination

Table 24 shows the inspection results of non-destructive examination and Table 25 shows the dimension of the cladding with connection endplug. It shows that all welded

components satisfy the criterion without any failures. Consequently, it was concluded that the welding of the pin components was successfully completed.

The overall bowings of the cladding with connection endplug were smaller than 0.5 mm as shown in Table 24. In the segment fabrication, the cladding with connection endplug for the upper and lower segment should be connected in accordance with the combination shown in the left (lower segment) and right (upper segment) side of this table to prevent the excessive bowing of the segment.

4. Summary

Based on the fabrication drawings [1] approved in JNC in cooperation with PSI and NRG, pin components for FUJI project were fabricated in JNC in accordance with ISO 9001. Additionally, the connection endplugs were welded to the claddings. The inspection showed all of the fabricated components satisfied the specifications. Welding of the connection endplugs were performed by the qualified procedure and the non-destructive examination of the welded joints showed the welding integrity was sufficient.

These products were delivered to PSI in October 2002 and will be used for the segment fabrication for FUJI project in PSI.

Reference

[1] Takayuki Ozawa “Fabrication Drawings of Fuel Pins for FUJI Project among PSI, JNC and NRG, JNC TY8410 2002-002 (2002)

Table 1 List of pin components and materials

Item	Material
Cladding tube	PNC1520
Upper endplug	PNC1520
Lower endplug	PNC1520
Connection endplug with a male screw	PNC1520
Connection endplug with a female screw	PNC1520
Plenum sleeve*	PNC1520
Plenum sleeve cap*	PNC1520
Plenum sleeve tube*	PNC1520
Special plenum sleeve**	PNC1520
Plenum sleeve cap 1**	PNC1520
Plenum sleeve cap 2**	PNC1520
Plenum sleeve tube**	PNC1520
Distance screw**	PNC1520
Fixation nut**	PNC1520
Spacer	PNC1520
Plenum spring*	SUS304-WPB
Fuel seal disc**	W

* Pellet fuel segment

** Sphere-pac or vipac fuel segment

Table 2 Number of pin components to be delivered

Item	Number of parts
Cladding with upper connection endplug	13
Cladding with lower connection endplug	10
Lower endplug	13
Upper endplug	10
Spacer	10
Plenum spring	7
Plenum sleeve	22
Special plenum sleeve	18
Fuel seal disc	24

Table 3 Composition of PNC1520

Element	Specified (wt%)	Composition of the product batch for the fabrication
C	0.04-0.08	0.056
Si	0.60-1.00	0.85
Mn	1.40-2.00	1.85
P	0.015-0.040	0.025
S	≤0.010	0.003
Fe	Balance	-
Ni	19.5-21.5	20.63
Cr	13.5-15.5	14.36
Mo	2.00-3.00	2.44
Co	≤0.05	0.02
B	0.0020-0.0060	0.0031
N	≤0.010	0.0055
Al	≤0.050	0.028
As	≤0.030	0.001
Ti	0.15-0.35	0.23
Nb	0.05-0.15	0.095
O	≤0.0040	0.0009
Cu	≤0.20	0.02
V	≤0.20	0.03
Zr	≤0.10	<0.01
Ta	≤0.05	<0.001

Table 4 Inspection method and criterion of the fabricated pin components (1/3)

Parts	Inspection item	Criterion	Inspection method
Upper endplug	Appearance	① No harmful stickiness (oil and fats, oxide, etc.) ② No return and burr on the end face ③ No visible crack and flaw ④ Dimension and surface roughness satisfy a fabrication drawing ⑤ Clean surface	Visual inspection
	Dimension	Within the fabrication tolerances	Dimensional inspection
Lower endplug	Appearance	① No harmful stickiness (oil and fats, oxide, etc.) ② No return and burr on the end face ③ No visible crack and flaw ④ Dimension and surface roughness satisfy a fabrication drawing ⑤ Clean surface	Visual inspection
	Dimension	Within the fabrication tolerances	Dimensional inspection
Plenum spring	Appearance	① No harmful stickiness (oil and fats, oxide, etc.) ② No return and burr on the end face ③ No visible crack and flaw ④ Dimension and surface roughness satisfy a fabrication drawing ⑤ Clean surface	Visual inspection
	Dimension	Within the fabrication tolerances	Dimensional inspection
Plenum sleeve	Appearance	① No harmful stickiness (oil and fats, oxide, etc.) ② No return and burr on the end face ③ No visible crack and flaw ④ Dimension and surface roughness satisfy a fabrication drawing ⑤ Clean surface ⑥ The spot weld should be sufficient	Visual inspection
	Dimension	Within the fabrication tolerances	Dimensional inspection
	Bowing	Pass through the inspection gauge (ID: 6.6 mm/ L: 20 mm)	Inspection gauge

Table 4 (continued) Inspection method and criterion of the fabricated pin components (2/3)

Parts	Inspection item	Criterion	Inspection method
Special plenum sleeve	Appearance	① No harmful stickiness (oil and fats, oxide, etc.) ② No return and burr on the end face ③ No visible crack and flaw ④ Dimension and surface roughness satisfy a fabrication drawing ⑤ Clean surface	Visual inspection
	Dimension	Within the fabrication tolerances *The assembled product with the maximal length should be mounted into cladding.	Dimensional inspection
Upper connection endplug	Appearance	① No harmful stickiness (oil and fats, oxide, etc.) ② No return and burr on the end face ③ No visible crack and flaw ④ Dimension and surface roughness satisfy a fabrication drawing ⑤ Clean surface	Visual inspection
	Dimension	Within the fabrication tolerances *Connection with the lower connection endplug should be examined.	Dimensional inspection
Lower connection endplug	Appearance	① No harmful stickiness (oil and fats, oxide, etc.) ② No return and burr on the end face ③ No visible crack and flaw ④ Dimension and surface roughness satisfy a fabrication drawing ⑤ Clean surface	Visual inspection
	Dimension	Within the fabrication tolerances *Connection with the upper connection endplug should be examined.	Dimensional inspection
Cladding tube	Appearance	① No harmful stickiness (oil and fats, oxide, etc.) ② No return and burr on the end face ③ No visible crack and flaw ④ Dimension and surface roughness satisfy a fabrication drawing ⑤ Clean surface	Visual inspection
	Dimension	Within the fabrication tolerances	Dimensional inspection

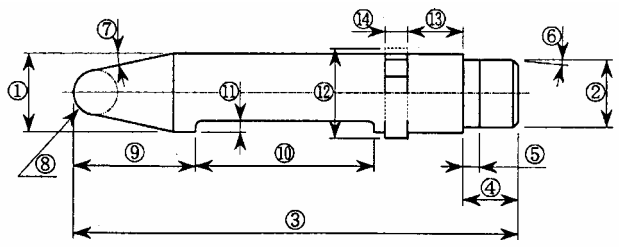
Table 4 (continued) Inspection method and criterion of the fabricated pin components (3/3)

Parts	Inspection item	Criterion	Inspection method
Spacer	Appearance	① No harmful stickiness (oil and fats, oxide, etc.) ② No return and burr on the end face ③ No visible crack and flaw ④ Dimension and surface roughness satisfy a fabrication drawing ⑤ Clean surface	Visual inspection
	Dimension	Within the fabrication tolerances	Dimensional inspection
Fuel seal disc	Appearance	① No harmful stickiness (oil and fats, oxide, etc.) ② No return and burr on the end face ③ No visible crack and flaw ④ Dimension and surface roughness satisfy a fabrication drawing ⑤ Clean surface	Visual inspection
	Dimension	Within the fabrication tolerances	Dimensional inspection

Table 5 Fabrication data of pin components (1) (upper endplug)

ID No.	①		②		③	④	⑤	⑥
	7.5 +0/-0.03		6.68±0.01		40±0.1	5±0.1	1.5± 0.1	2±0.5
	X	Y	X	Y				
SPFI11	7.49	7.48	6.69	6.69	40.0	5.0	1.5	2.0
SPFI12	7.49	7.49	6.69	6.69	40.0	5.0	1.5	1.9
SPFR11	7.49	7.49	6.69	6.69	40.0	5.0	1.5	1.9
SPFR12	7.48	7.48	6.69	6.69	40.0	5.0	1.4	2.0
SPFR21	7.48	7.48	6.68	6.69	40.0	5.0	1.5	2.0
SPFR22	7.48	7.48	6.69	6.69	40.0	5.0	1.5	2.0
SPFP11	7.49	7.49	6.69	6.69	40.0	5.0	1.5	2.0
SPFP12	7.49	7.49	6.68	6.69	40.0	5.0	1.5	2.0
004	7.49	7.49	6.68	6.68	40.0	5.0	1.5	2.0
017	7.49	7.49	6.69	6.68	40.0	5.0	1.5	2.0

ID No.	⑦	⑧	⑨	⑩	⑪	⑫	⑬	⑭
	15±0.5	2±0.1	11 +0.2/-0	16 +0.5/-0	0.7±0.1	8.3± 0.03	5±0.1	2±0.1
SPFI11	14.8	2.0	11.0	16.3	0.7	8.30	5.0	2.0
SPFI12	14.9	2.0	11.0	16.3	0.7	8.30	5.0	2.0
SPFR11	14.8	2.0	11.0	16.3	0.7	8.30	5.0	2.0
SPFR12	14.8	2.0	11.0	16.3	0.7	8.30	5.0	2.0
SPFR21	14.9	2.0	11.0	16.3	0.7	8.30	5.0	2.0
SPFR22	14.8	2.0	11.1	16.3	0.7	8.30	5.0	2.0
SPFP11	14.9	2.0	11.1	16.3	0.7	8.30	5.0	2.0
SPFP12	14.8	2.0	11.1	16.3	0.7	8.30	5.0	2.0
004	14.7	2.0	11.1	16.3	0.7	8.30	5.0	2.0
017	14.8	2.0	11.1	16.3	0.7	8.30	5.0	2.0

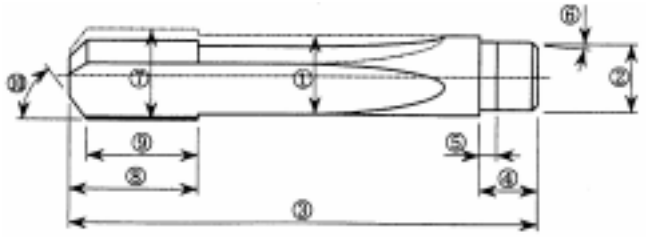


* Upper endplugs with the upper limit of the diameter ② were selected for use.

Table 6 Fabrication data of pin components (2) (lower endplug)

ID No.	①		②		③	④	⑤	⑥
	7.5 +0/-0.03		6.68±0.01		40±0.1	5±0.1	1.5±0.1	2±0.5
	X	Y	X	Y				
001	7.49	7.49	6.69	6.69	40.0	5.0	1.6	2.1
002	7.48	7.48	6.68	6.68	40.0	5.0	1.5	1.9
003	7.48	7.48	6.69	6.69	40.0	5.0	1.5	2.0
004	7.48	7.48	6.68	6.68	40.0	5.0	1.6	2.0
005	7.48	7.48	6.69	6.69	40.0	5.0	1.5	2.0
006	7.49	7.49	6.68	6.68	40.0	5.0	1.6	1.9
007	7.48	7.48	6.69	6.69	40.0	5.0	1.5	2.0
008	7.49	7.49	6.68	6.68	40.0	5.0	1.6	1.9
010	7.49	7.49	6.69	6.69	40.0	5.0	1.5	2.0
015	7.49	7.49	6.69	6.69	40.0	5.0	1.5	2.1
022	7.49	7.49	6.69	6.69	40.0	5.0	1.6	2.0
024	7.49	7.49	6.69	6.69	40.0	5.0	1.6	2.0
025	7.49	7.49	6.69	6.69	40.0	5.0	1.5	2.1

ID No.	⑦	⑧	⑨	⑩
	8.3±0.03	11±0.1	9.5±0.1	60±0.5
001	8.30	11.0	9.5	60.2
002	8.30	11.0	9.5	60.1
003	8.30	11.0	9.5	59.8
004	8.30	11.0	9.5	59.8
005	8.30	11.0	9.5	59.6
006	8.30	11.1	9.6	59.8
007	8.30	11.0	9.5	59.6
008	8.30	11.0	9.5	60.2
010	8.30	11.0	9.5	60.2
015	8.31	11.0	9.5	59.6
022	8.29	11.0	9.5	60.1
024	8.30	11.0	9.5	60.1
025	8.30	11.0	9.5	60.1



* Lower endplugs with the upper limit of the diameter ② were selected for use.

Table 7 Fabrication data of pin components (3) (plenum spring)

ID No.	①		②	Spring constant	Effective turns	Total turns	Coil direction
	6.4±0.1		100±2	0.642± 0.042			
	X	Y			53	55	Clockwise
001	6.4	6.4	OK	0.662	OK	OK	OK
002	6.4	6.4	OK	0.667	OK	OK	OK
003	6.4	6.4	OK	0.657	OK	OK	OK
004	6.4	6.4	OK	0.657	OK	OK	OK
005	6.4	6.4	OK	0.657	OK	OK	OK
006	6.4	6.4	OK	0.657	OK	OK	OK
007	6.4	6.4	OK	0.662	OK	OK	OK

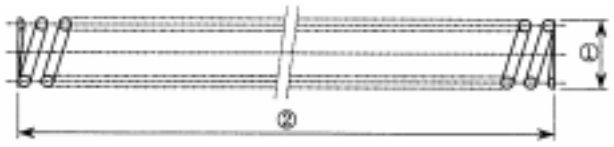


Table 8 Fabrication data of pin components (4) (plenum sleeve)

ID No.	①	②	Bowing	ID No.	①	②	Bowing
	6.6 max	50±0.3	Gauge		6.6 max	50±0.3	Gauge
001	<6.6	50.0	Through	012	<6.6	50.0	Through
002	<6.6	50.0	Through	013	<6.6	50.0	Through
003	<6.6	49.9	Through	014	<6.6	50.0	Through
004	<6.6	49.9	Through	015	<6.6	50.0	Through
005	<6.6	49.9	Through	016	<6.6	50.0	Through
006	<6.6	49.9	Through	017	<6.6	49.9	Through
007	<6.6	50.0	Through	018	<6.6	49.9	Through
008	<6.6	50.0	Through	019	<6.6	49.9	Through
009	<6.6	49.9	Through	020	<6.6	50.0	Through
010	<6.6	49.9	Through	021	<6.6	50.0	Through
011	<6.6	50.0	Through	022	<6.6	50.0	Through

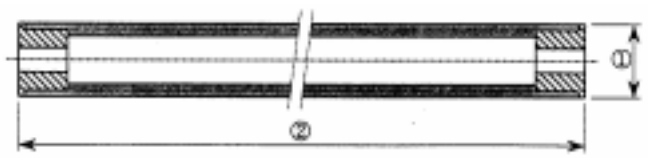


Table 9 Fabrication data of pin components (5) (plenum sleeve for special plenum sleeve)

ID No.	①	②	Bowing**	ID No.	①	②	Bowing*
	6.6 max	71.7 ±0.3	Gauge		6.6 max	71.7 ±0.3	Gauge
001	<6.6	71.6	Through	013	<6.6	71.7	Through
002	<6.6	71.7	Through	014	<6.6	71.6	Through
004	<6.6	71.7	Through	015	<6.6	71.7	Through
007	<6.6	71.7	Through	016	<6.6	71.7	Through
008	<6.6	71.7	Through	017	<6.6	71.7	Through
009	<6.6	71.7	Through	018	<6.6	71.7	Through
010	<6.6	71.7	Through	019	<6.6	71.7	Through
011	<6.6	71.7	Through	020	<6.6	71.6	Through
012	<6.6	71.7	Through	021	<6.6	71.7	Through

* It was inspected each special plenum sleeve including a distance screw (127mm) could pass through a cladding.

** All special plenum sleeves to be delivered were assembled with a plenum sleeve, a distance screw and a fixation nut, which have the same ID No.

Table 10 Fabrication data of pin components (6) (distance screw for special plenum sleeve)

ID No.	①		②	③	④	ID No.	①		②	③	④
	6.2±0.02		60± 0.2	5±0.1	M3		6.2±0.02		60± 0.2	5±0.1	M3
	X	Y					X	Y			
001	6.22	6.22	60.1	5.0	OK	013	6.21	6.21	60.1	5.0	OK
002	6.22	6.22	60.1	5.0	OK	014	6.21	6.21	60.1	5.0	OK
004	6.21	6.21	60.1	5.0	OK	015	6.21	6.21	60.1	5.0	OK
007	6.21	6.21	60.1	4.9	OK	016	6.20	6.20	60.1	5.0	OK
008	6.21	6.21	60.1	5.0	OK	017	6.21	6.21	60.1	5.0	OK
009	6.21	6.21	60.1	5.0	OK	018	6.20	6.20	60.1	5.0	OK
010	6.21	6.21	60.1	5.0	OK	019	6.20	6.21	60.1	5.0	OK
011	6.22	6.21	60.1	5.0	OK	020	6.21	6.21	60.1	5.0	OK
012	6.22	6.22	60.1	5.0	OK	021	6.21	6.20	60.0	5.0	OK

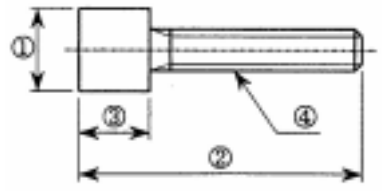


Table 11 Fabrication data of pin components (7) (fixation nut for special plenum sleeve)

ID No.	① 6.2±0.02	② 5±0.1	③ 3±0.1	④ M3	ID No.	① 6.2±0.02	② 5±0.1	③ 3±0.1	④ M3
001	6.21	5.0	3.0	OK	013	6.21	5.0	3.0	OK
002	6.21	5.0	3.0	OK	014	6.20	5.0	3.0	OK
004	6.21	5.0	3.0	OK	015	6.20	5.0	3.0	OK
007	6.21	5.0	3.0	OK	016	6.21	5.0	3.0	OK
008	6.21	5.0	3.0	OK	017	6.21	5.0	3.0	OK
009	6.21	5.0	3.0	OK	018	6.21	5.0	3.0	OK
010	6.21	5.0	3.0	OK	019	6.21	5.0	3.0	OK
011	6.21	5.0	3.0	OK	020	6.21	5.0	3.0	OK
012	6.21	5.0	3.0	OK	021	6.21	5.0	3.0	OK

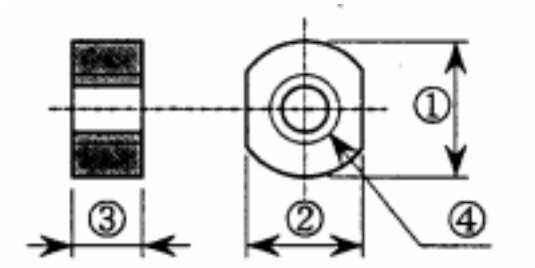


Table 12 Fabrication data of pin components (8) (upper connection endplug)

ID No.	①		②		③	④	⑤	⑥	⑦	⑧
	7.5 +0/-0.03		6.68±0.01		19.9±0.1	5±0.1	1.5±0.1	2±0.5	6.9±0.1	1.9 +0/0.05
	X	Y	X	Y						
001	7.48	7.48	6.69	6.69	19.9	5.0	1.6	2.0	6.9	1.88
005	7.49	7.49	6.69	6.69	19.9	5.0	1.6	2.0	6.9	1.88
006	7.49	7.49	6.68	6.69	19.9	5.0	1.5	2.0	6.9	1.87
007	7.48	7.48	6.69	6.69	19.9	5.0	1.6	2.0	6.9	1.88
008	7.48	7.48	6.69	6.69	19.9	5.0	1.5	2.0	6.9	1.87
014	7.49	7.49	6.69	6.69	19.9	5.0	1.5	1.9	6.9	1.88
027	7.49	7.49	6.69	6.69	19.9	5.0	1.6	2.0	6.9	1.87
031	7.49	7.49	6.69	6.69	19.9	5.0	1.5	2.0	6.9	1.88
037	7.49	7.49	6.69	6.69	19.9	5.0	1.5	2.0	6.9	1.88
038	7.49	7.49	6.69	6.69	19.9	5.0	1.5	2.0	6.9	1.87
040	7.49	7.49	6.69	6.69	19.9	5.0	1.5	1.9	6.9	1.87
042	7.48	7.48	6.69	6.69	19.9	5.0	1.5	1.9	6.9	1.88
043	7.49	7.49	6.69	6.69	19.9	5.0	1.5	2.0	6.9	1.87

ID No.	⑨		⑩		⑪		⑫	⑬
	4.5 +0/-0.01		1.5±0.1		4.5±0.1		6±0.1	M4
	X	Y	A	B	A	B		
001	4.50	4.50	1.5	1.4	4.5	4.5	6.0	OK
005	4.49	4.49	1.4	1.5	4.6	4.6	6.0	OK
006	4.50	4.49	1.4	1.5	4.6	4.6	6.0	OK
007	4.50	4.50	1.5	1.4	4.6	4.6	6.0	OK
008	4.50	4.50	1.5	1.5	4.6	4.6	6.0	OK
014	4.50	4.49	1.4	1.5	4.6	4.6	6.1	OK
027	4.50	4.50	1.4	1.5	4.5	4.5	6.1	OK
031	4.50	4.50	1.5	1.4	4.6	4.6	6.1	OK
037	4.50	4.50	1.5	1.5	4.6	4.6	6.1	OK
038	4.50	4.50	1.5	1.4	4.6	4.6	6.1	OK
040	4.50	4.50	1.5	1.4	4.6	4.6	6.1	OK
042	4.50	4.50	1.5	1.4	4.6	4.6	6.1	OK
043	4.50	4.50	1.5	1.5	4.5	4.5	6.1	OK

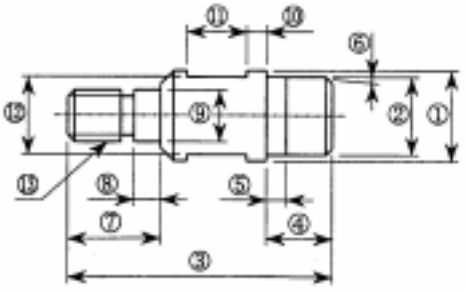


Table 13 Fabrication data of pin components (9) (lower connection endplug)

ID No.	①		②		③	④	⑤	⑥
	7.5 +0/-0.03		6.68±0.01		15±0.1	5±0.1	1.5±0.1	2±0.5
	X	Y	X	Y				
001	7.49	7.49	6.68	6.68	15.0	5.0	1.4	1.9
004	7.49	7.49	6.69	6.69	15.0	5.0	1.4	1.9
005	7.49	7.49	6.68	6.68	15.0	5.0	1.5	2.0
009	7.49	7.49	6.69	6.69	15.0	5.0	1.6	1.9
013	7.49	7.49	6.68	6.68	15.0	5.0	1.6	2.0
016	7.49	7.49	6.68	6.68	15.0	5.0	1.5	1.9
018	7.49	7.49	6.68	6.68	15.0	5.0	1.6	2.0
019	7.49	7.49	6.68	6.68	15.0	5.0	1.5	2.0
020	7.49	7.49	6.68	6.68	15.0	5.0	1.5	2.0
021	7.49	7.49	6.68	6.68	15.0	5.0	1.5	1.9

ID No.	⑦		⑧		⑨	⑩	⑪
	2.5±0.1		4.5±0.1		6±0.1	(8)	M4
	A	B	A	B			
001	2.5	2.5	4.5	4.5	6.0	9.0	OK
004	2.5	2.5	4.5	4.5	6.0	9.0	OK
005	2.5	2.5	4.5	4.5	6.0	9.1	OK
009	2.5	2.5	4.5	4.5	6.0	9.1	OK
013	2.5	2.5	4.5	4.5	6.0	9.1	OK
016	2.5	2.5	4.5	4.5	6.0	9.0	OK
018	2.4	2.5	4.5	4.5	6.0	9.0	OK
019	2.5	2.5	4.5	4.5	6.0	9.0	OK
020	2.5	2.5	4.5	4.5	6.0	9.1	OK
021	2.5	2.5	4.5	4.5	6.0	9.1	OK

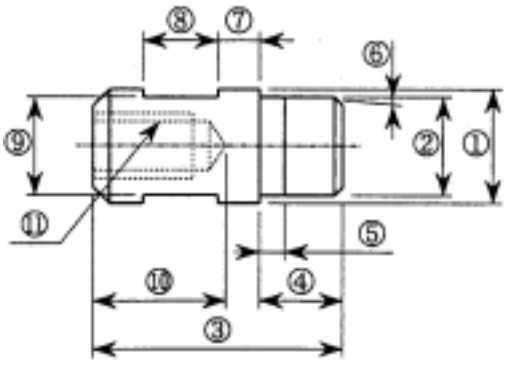


Table 14 Fabrication data of pin components (10) (cladding tube)

(a) Lower segment

ID No.	Length	Outer diameter		Inner diameter	
		MAX	MIN	MAX	MIN
022-01	410.0	7.493	7.487	6.700	6.682
023-02	410.0	7.498	7.491	6.699	6.682
023-03	410.0	7.498	7.491	6.699	6.682
024-01	410.0	7.496	7.489	6.698	6.684
024-02	410.0	7.496	7.489	6.698	6.684
025-03	410.0	7.500	7.495	6.697	6.684
027-02	410.0	7.496	7.486	6.695	6.678
027-03	410.0	7.496	7.486	6.695	6.678
029-01	410.0	7.499	7.482	6.692	6.675
029-02	410.0	7.499	7.482	6.692	6.675
029-03	410.0	7.499	7.482	6.692	6.675
030-02	410.0	7.500	7.493	6.700	6.687
030-03	410.0	7.500	7.493	6.700	6.687

(b) Upper segment

ID No.	Length	Outer diameter		Inner diameter	
		MAX	MIN	MAX	MIN
031-02	410.0	7.498	7.492	6.701	6.684
032-02	410.0	7.491	7.484	6.696	6.679
032-03	410.0	7.491	7.484	6.696	6.679
034-01	410.0	7.499	7.493	6.697	6.686
037-02	410.0	7.495	7.487	6.703	6.686
037-01	410.0	7.495	7.487	6.703	6.686
036-02	410.0	7.498	7.491	6.698	6.684
035-02	410.0	7.500	7.495	6.700	6.686
038-01	410.0	7.496	7.487	6.695	6.681
037-03	410.0	7.495	7.487	6.703	6.686

Table 15 Fabrication data of pin components (11) (spacer)

ID No.	①	②	③		④	⑤		
	7.9± 0.03	5.5± 0.05	4.5 +0.01/-0		2 +0.05/-0	2±0.1		
			X	Y		A	B	C
001	7.91	5.50	4.51	4.51	2.03	2.0	2.0	2.0
002	7.91	5.50	4.51	4.51	2.02	2.0	2.0	2.0
003	7.91	5.50	4.51	4.51	2.03	2.0	2.0	2.0
004	7.91	5.51	4.51	4.51	2.03	2.0	2.0	2.0
005	7.90	5.50	4.51	4.51	2.04	2.0	2.0	2.0
006	7.91	5.50	4.51	4.51	2.03	2.0	2.0	2.0
007	7.90	5.50	4.51	4.51	2.03	2.0	2.0	2.0
008	7.91	5.51	4.51	4.51	2.02	2.0	2.0	2.0
009	7.90	5.50	4.51	4.51	2.04	2.0	2.0	2.0
010	7.91	5.50	4.51	4.51	2.02	2.0	2.0	2.0

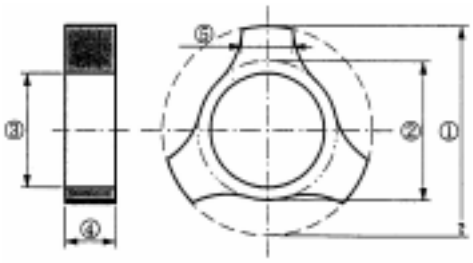


Table 16 Fabrication data of pin components (12) (fuel seal disc)

ID No.	①		②	ID No.	①		②
	6.65± 0.015		0.1 ± 0.05		6.65± 0.015 Y		0.1 ± 0.05
	X	Y			X		
011	6.660	6.661	0.11	047	6.660	6.663	0.10
017	6.661	6.662	0.10	052	6.662	6.663	0.10
020	6.658	6.660	0.10	055	6.660	6.659	0.10
023	6.659	6.658	0.10	056	6.663	6.660	0.10
025	6.660	6.659	0.11	057	6.664	6.660	0.10
032	6.659	6.663	0.11	060	6.662	6.661	0.10
033	6.658	6.660	0.10	061	6.659	6.663	0.10
037	6.658	6.661	0.10	074	6.658	6.663	0.11
039	6.659	6.658	0.10	075	6.658	6.660	0.11
043	6.662	6.661	0.10	078	6.658	6.658	0.10
045	6.659	6.660	0.10	080	6.660	6.660	0.11
046	6.659	6.658	0.10	082	6.658	6.662	0.10

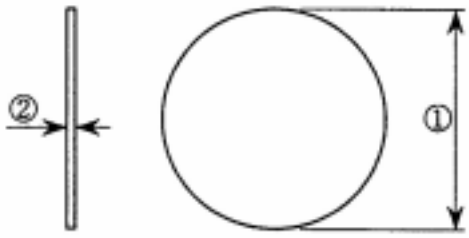


Table 17 Welding conditions

Welding conditions	Welding atmosphere	He-Ar	Pre-heating of welding zone	not performed
	Current (A)	19.0 – 17.0	Arc gap (mm)	0.2
	Voltage (V)	16 – 19	Position of electrode	connected zone
	Rotating speed (rpm)	20	Angle of torch (degree)	30
	Welding time (s)	1.0-5.0-4.0-1.5 (total 11.5)	Chill	not used

Table 18 Dimension of welding specimen for qualification test

Specimen	Dimension
Cladding	7.5mm $\phi \times 100$ mm *l* (shorter than the actual one)
Upper connection endplug	7.5mm $\phi \times 15$ mm *l*

Table 19 Specimen ID for welding qualification test

Specimen ID	Upper connection endplug	Cladding lot No.
002	002	8AK3-019
003	003	8AK3-019
011	011	8AK3-019
015	015	8AK3-020
020	020	8AK3-020
021	021	8AK3-020
022	022	8AK3-021
023	023	8AK3-021
025	025	8AK3-021
026	026	8AK3-021

Table 20 Non-destructive examination and its criteria for qualification test

Inspection item	Criteria	Method	Number of specimens
Appearance of welded zone	(1) No remarkable coloring (2) No undercut (3) No pinhole, crack (4) Constant bead width	Visual inspection	10
Dimension of welded zone	Bead diameter should be smaller than 7.65 mm	Dimension measurement	10
X-ray radiography	(1) No blowhole exceeding 0.2 mmϕ (2) Welding depth should be larger than cladding thickness	X-ray radiography (0, 90 °)	10

Table 21 Destructive examination and its criteria for qualification test

Inspection item	Criteria	Method	Number of specimens
Burst test	Burst pressure should be higher than 74 MPa at the room temperature.	Inner pressurizing	3
Tensile test	Tensile strength should be higher than 4903 N at the room temperature.	Tensile testing	3
Metallography	Welding depth should be larger than cladding thickness	Microscope	3

Table 22 Result of non-destructive examination for qualification test

Specimen ID	Visual inspection				Bead diameter (< 7.65 mm)	X-ray radiography
	Coloring	Undercut	Pinhole, crack	Bead width		
002	OK	OK	OK	OK	7.630	OK
003	OK	OK	OK	OK	7.644	OK
011	OK	OK	OK	OK	7.613	OK
015	OK	OK	OK	OK	7.640	OK
020	OK	OK	OK	OK	7.635	OK
021	OK	OK	OK	OK	7.644	OK
022	OK	OK	OK	OK	7.643	OK
023	OK	OK	OK	OK	7.623	OK
025	OK	OK	OK	OK	7.621	OK
026	OK	OK	OK	OK	7.646	OK

Table 23 Result of destructive examination for qualification test

Bust test (Burst pressure should be higher than 74 MPa)				
Specimen ID	Temperature	Pressurizing rate (MPa/min)	Burst pressure (MPa)	Burst position
011	Room temperature	17.5	101.5	Cladding
021			101.0	Cladding
022			100.0	Cladding
Tensile test (Tensile strength should be higher than 4903 N)				
Specimen ID	Temperature	Pulling rate (mm/min)	Tensile strength (N)	Broken position
002	Room temperature	2.5	5932.5	Cladding
015			5865.0	Cladding
023			5837.5	Cladding
Metallographic inspection				
Specimen ID	Magnification	Result		
003	×50	OK		
020		OK		
026		OK		

Table 24 Result of non-destructive examination on welded components for delivery

Cladding with Upper Connection Endplug (Lower Segment)					Cladding with Lower Connection Endplug (Upper Segment)				
Cladding ID	E/P ID	Bead diameter (mm)	Visual examination	X-ray examination	Cladding ID	E/P ID	Bead diameter (mm)	Visual examination	X-ray examination
022-01	001	7.613	None	None	031-02	001	7.601	None	None
023-02	005	7.601	None	None	032-02	004	7.596	None	None
023-03	006	7.607	None	None	032-03	005	7.597	None	None
024-01	007	7.602	None	None	034-01	009	7.592	None	None
024-02	008	7.604	None	None	037-02	019	7.609	None	None
025-03	014	7.646	None	None	037-01	018	7.596	None	None
027-02	027	7.608	None	None	036-02	016	7.605	None	None
027-03	031	7.600	None	None	035-02	013	7.600	None	None
029-01	037	7.598	None	None	038-01	021	7.597	None	None
029-02	038	7.595	None	None	037-03	020	7.592	None	None
029-03	040	7.593	None	None					
030-02	042	7.628	None	None					
030-03	043	7.605	None	None					

Table 24(continued) **Result of non-destructive examination on welded components for delivery**

Cladding with Upper Connection Endplug (Lower Segment)				Cladding with Lower Connection Endplug (Upper Segment)				Bowing
Cladding ID	E/P ID	Back ground (Pa・m^3/sec)	Leakage (Pa・m^3/sec)	Cladding ID	E/P ID	Back ground (Pa・m^3/sec)	Leakage (Pa・m^3/sec)	
022-01	001	0.42×10^{-9}	0.38×10^{-9}	031-02	001	0.25×10^{-9}	0.22×10^{-9}	< 0.50 mm
023-02	005	0.33×10^{-9}	0.32×10^{-9}	032-02	004	0.24×10^{-9}	0.22×10^{-9}	< 0.50 mm
023-03	006	0.36×10^{-9}	0.34×10^{-9}	032-03	005	0.25×10^{-9}	0.22×10^{-9}	< 0.50 mm
024-01	007	0.29×10^{-9}	0.26×10^{-9}	034-01	009	0.26×10^{-9}	0.23×10^{-9}	< 0.50 mm
024-02	008	0.47×10^{-9}	0.47×10^{-9}	037-02	019	0.45×10^{-9}	0.45×10^{-9}	< 0.50 mm
025-03	014	0.28×10^{-9}	0.26×10^{-9}	037-01	018	0.45×10^{-9}	0.44×10^{-9}	< 0.50 mm
027-02	027	0.26×10^{-9}	0.24×10^{-9}	036-02	016	0.40×10^{-9}	0.40×10^{-9}	< 0.50 mm
027-03	031	0.45×10^{-9}	0.44×10^{-9}	035-02	013	0.37×10^{-9}	0.35×10^{-9}	< 0.50 mm
029-01	037	0.45×10^{-9}	0.41×10^{-9}	038-01	021	0.22×10^{-9}	0.20×10^{-9}	< 0.50 mm
029-02	038	0.39×10^{-9}	0.35×10^{-9}	037-03	020	0.46×10^{-9}	0.42×10^{-9}	< 0.50 mm
029-03	040	0.36×10^{-9}	0.34×10^{-9}					
030-02	042	0.36×10^{-9}	0.32×10^{-9}					
030-03	043	0.33×10^{-9}	0.29×10^{-9}					

Table 25 Dimension of the cladding with connection endplug

(a) The cladding with upper connection endplug (for lower segment).

ID No.	E/P ID	Cladding					Segment length (mm)
		Length (mm)	Outer diameter (mm)		Inner diameter (mm)		
			MAX	MIN	MAX	MIN	
022-01	001	410.0	7.493	7.487	6.700	6.682	424.9
023-02	005	410.0	7.498	7.491	6.699	6.682	424.9
023-03	006	410.0	7.498	7.491	6.699	6.682	424.9
024-01	007	410.0	7.496	7.489	6.698	6.684	424.9
024-02	008	410.0	7.496	7.489	6.698	6.684	424.9
025-03	014	410.0	7.500	7.495	6.697	6.684	424.9
027-02	027	410.0	7.496	7.486	6.695	6.678	424.9
027-03	031	410.0	7.496	7.486	6.695	6.678	424.9
029-01	037	410.0	7.499	7.482	6.692	6.675	424.9
029-02	038	410.0	7.499	7.482	6.692	6.675	424.9
029-03	040	410.0	7.499	7.482	6.692	6.675	424.9
030-02	042	410.0	7.500	7.493	6.700	6.687	424.9
030-03	043	410.0	7.500	7.493	6.700	6.687	424.9

(b) The cladding with lower connection endplug (for upper segment).

ID No.	E/P ID	Cladding					Segment length (mm)
		Length (mm)	Outer diameter (mm)		Inner diameter (mm)		
			MAX	MIN	MAX	MIN	
031-02	001	410.0	7.498	7.492	6.701	6.684	420.0
032-02	004	410.0	7.491	7.484	6.696	6.679	420.0
032-03	005	410.0	7.491	7.484	6.696	6.679	420.0
034-01	009	410.0	7.499	7.493	6.697	6.686	420.0
037-02	019	410.0	7.495	7.487	6.703	6.686	420.0
037-01	018	410.0	7.495	7.487	6.703	6.686	420.0
036-02	016	410.0	7.498	7.491	6.698	6.684	420.0
035-02	013	410.0	7.500	7.495	6.700	6.686	420.0
038-01	021	410.0	7.496	7.487	6.695	6.681	420.0
037-03	020	410.0	7.495	7.487	6.703	6.686	420.0

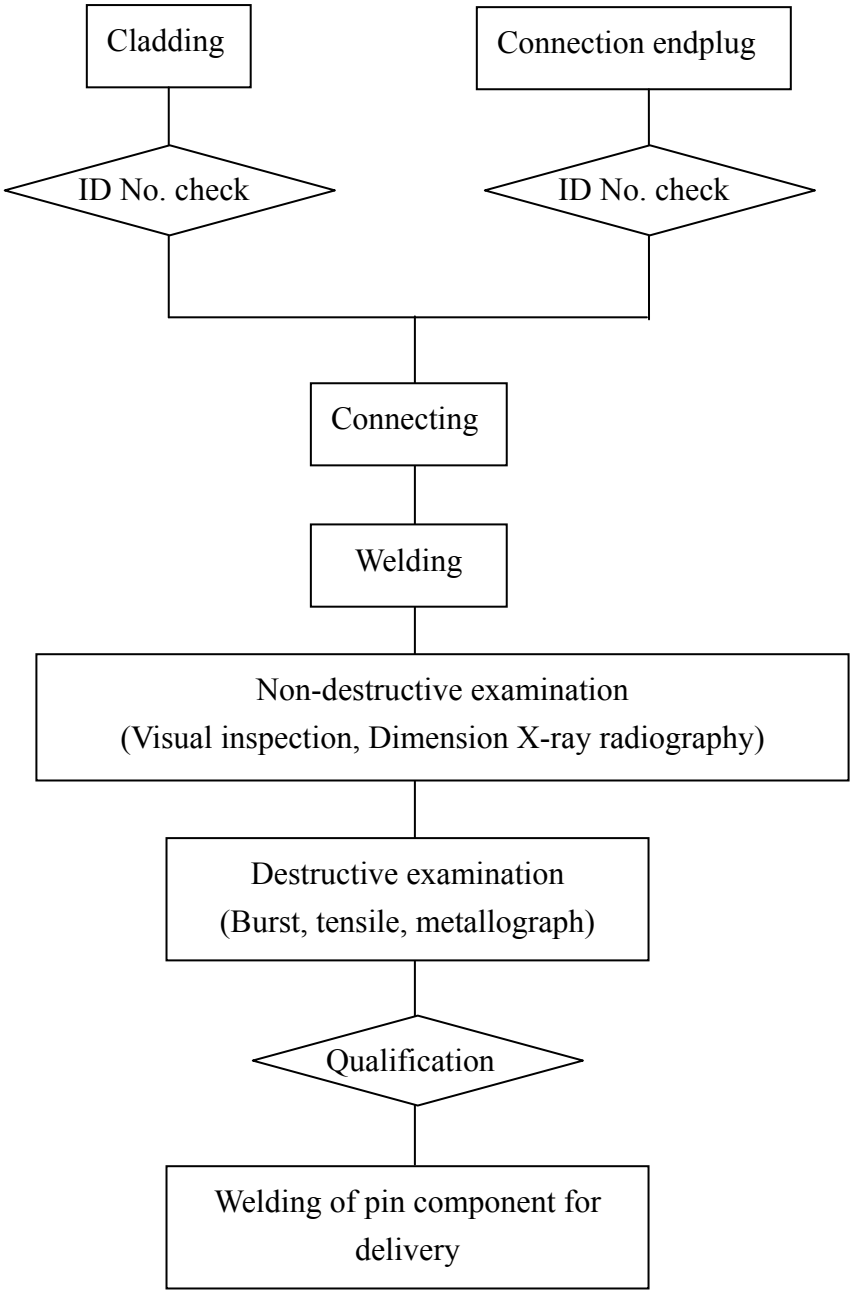


Fig. 1 Procedure of welding qualification

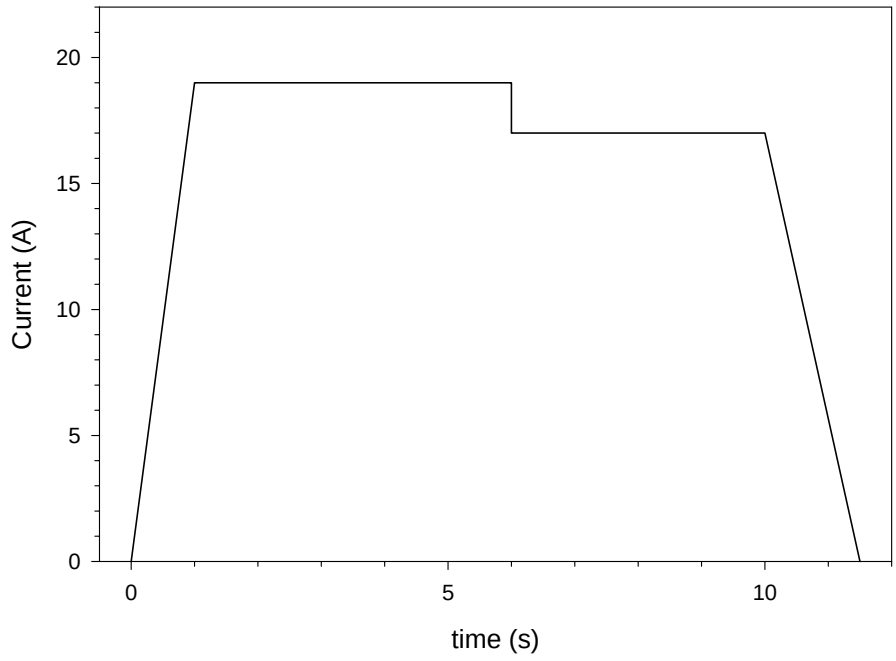
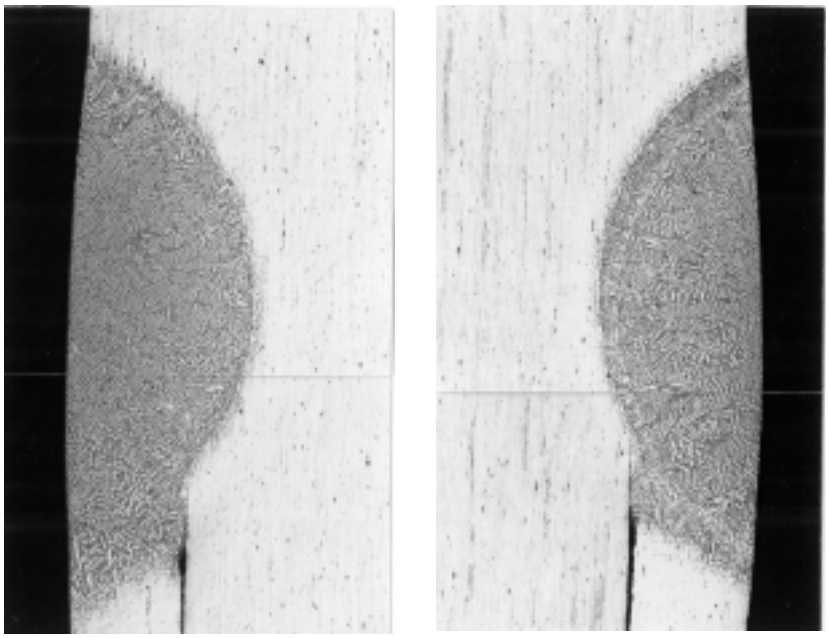
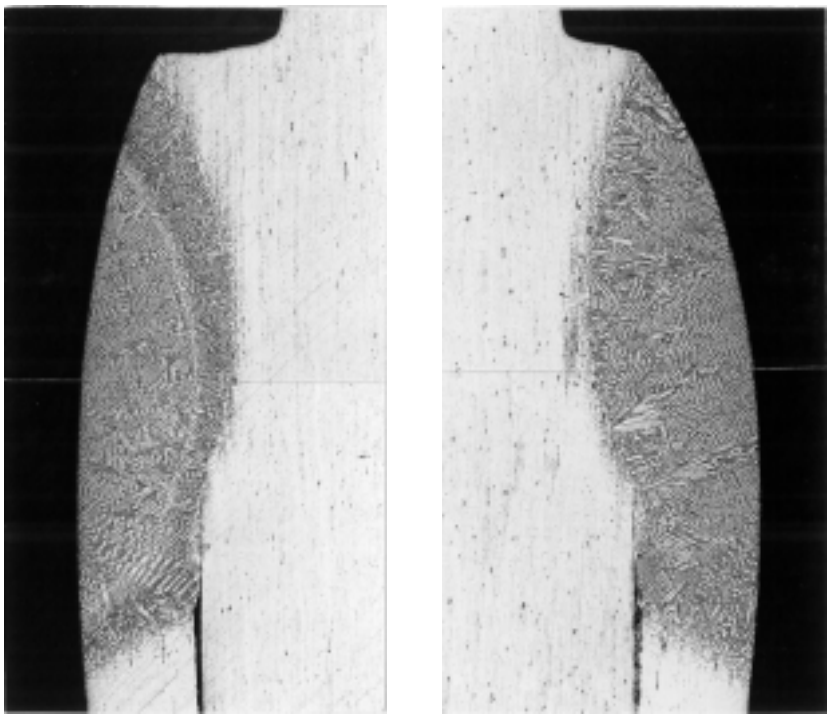


Fig. 2 Welding current chart

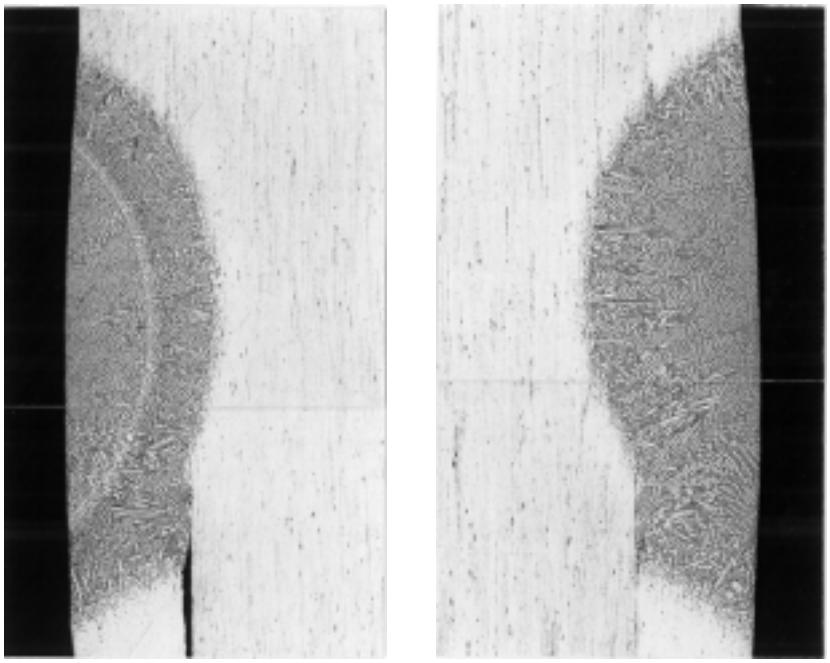


(a) No.3

Fig. 3 Metallographic image of welded zone



(b) No.20



(c) No.26

Fig. 3 (continued) Metallographic image of welded zone