Guideline No.: W-24(202311)

W-24

FRICTION STIR WELDED ALUMINUM ALLOY STIFFENED PLATE

Issued date: November 10, 2023

Foreword

China Classification Society (hereinafter referred to as CCS) Product Inspection and Testing Guideline (hereinafter referred to as this Guideline) contains the technical requirements, inspection and testing criteria related to classification and statutory survey of marine products to be applied for CCS approval/inspection.

This Guideline frees the users to adopt other test methods and requirements which are equivalent to or are stricter than this Guideline.

This Guideline is published and updated by CCS, and is released at http://www.ccs.org.cn. Your comments or suggestions are welcomed and may be sent to our email addressed mp@ccs.org.cn

Historical versions and release date: Initial release

Main changes: Nil.

CONTENT

Friction Stir Welded Aluminum Alloy Stiffened Panel

1 Application

1.1 This Guidelines is applicable to the works approval and product inspection of friction stir welded aluminum alloy stiffened panel manufactured in accordance with the Rules for Classification of Sea-going Steel Ships and the Rules for Materials and Welding of the Society. For the friction stir welding of aluminum alloy rolled plates, may refer to the requirements of this Guidelines.

1.2 This Guidelines is applicable to butt welds of extruded aluminum alloy stiffened panels, rather than other types of joints.

2 Normative References

(1) Rules for Materials and Welding, China Classification Society

(2) Rules for Classification of Sea-going Steel Ships, China Classification Society

(3) ISO 25239 Friction stir welding – Aluminum

(4) GB/T 34630.1 Friction stir welding - Aluminum and its alloys - Part 1: Terminology and definition.

(5) ASME BPVC Sec. IX Welding, Brazing, and Fusing Qualifications

(6) AWS D17.3/D17.3M Specification for Friction Stir Welding of Aluminum Alloys for Aerospace Applications

(7) ISO 17637 Non-destructive testing of welds –Visual testing of fusion-welded joints

(8) GB/T 32259 Non-destructive testing of welds-Visual testing of fusion-welded joints

(9) ISO 23277 Non-destructive testing of welds–Penetrant testing– Acceptance levels

(10) CB/T 3929 X-ray inspection and quality classification for welded butt joints on aluminum alloy hull

(11) NB/T 47013.2 Nondestructive testing of pressure equipment - Part 2：Radiographic testing

(12) NB/T 47013.3 Nondestructive testing of pressure equipment - Part 3: Ultrasonic testing

(13) JIS Z 3080 Methods of ultrasonic angle beam examination for butt welds of aluminum plates

3 Terms and Definitions

3.1 Friction stir welding (FSW): a solid-state joining method that involves mechanical force and frictional heat. The metal at the faying surface is plasticized under the frictional heat between the FSW tool and its shoulder and the weldment, which flows backwards and fills to form a solid-state weld under the combined traction and stirring action of the FSW tool and its shoulder.

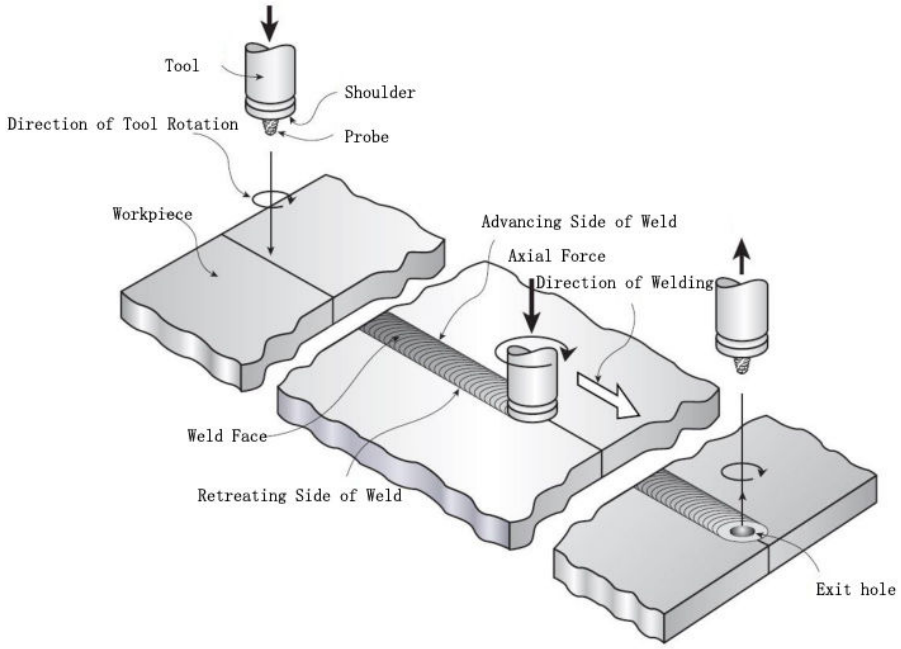


Figure 3.1 Schematic Diagram of Friction Stir Welding

3.2 FSW tool: a rotating part consisting of a probe and a shoulder for the friction stir welding. As shown in the figure, it usually consists of one (or more) probes and shoulders, or no shoulder or probe.

3.3 Probe: the part of the FSW tool inserted into the parent metal for the friction stir welding.

3.4 Shoulder: the part of the FSW tool connected to the root of the probe, which contacts and acts on the surface of the parent metal during the welding.

3.5 Axial force: the force applied to the workpiece along the axial direction of the FSW tool during the welding.

3.6 Plunge depth: the depth that the lowest point of the shoulder is plunged into the surface of the parent metal during the welding.

3.7 Tilt angle: the angle between the centerline of the FSW tool and the normal to the workpiece surface on the plane parallel to the welding direction.

3.8 Side tilt angle: the angle between the centerline of the FSW tool and the normal to the workpiece surface on the plane perpendicular to the welding direction.

3.9 Surface pit: the phenomenon that the surface of the weld is lower than that of the adjacent parent metal after the friction stir welding.

3.10 Incomplete penetration: the phenomenon that the welding depth is less than the required (or specified) depth, which usually causes plastic deformation in the area, with the materials closely contacted but not effectively bonded.

3.11 Toe flash: the metal residue that appears on the joint surface and curls along the weld toe during the welding.

3.12 Cavity: the tunnel-shaped hole formed inside the weld along the welding direction.

3.13 Linear misalignment: the deviation caused by the failure to meet the specified parallel alignment requirements when the surfaces of two weldments should be aligned in parallel.

3.14 Subsidence: the phenomenon that the metal at the root of the butt weld protrudes too high from the lower surface of the weld.

3.15 Dwell time: the time interval from the insertion of the FSW tool into the parent metal to the maximum depth to the start of movement.

4 Drawings and documents

The manufacturer shall submit the following data, drawings and technical documents when applying for the initial approval of products to the Society:

4.1 Manufacturer overview: including manufacturer's name, address, production history, production capacity, main products, legal representative, business license, ISO9000 quality system certificate, list of personnel in key technical management positions such as inspection, testing, welding, nondestructive testing personnel and main technical management personnel, and their required certificates or qualifications, etc.

4.2 Details of products applied for approval: alloy designation, alloy temper, thickness range and maximum length.

4.4 List of main production equipment, including the technical parameters related to the following equipment:

(1) Friction stir welding machine: welding thickness range, maximum width, maximum length, spindle speed, axial force and other parameters;

(2) Heat treatment equipment (if any): size, heating method, furnace temperature measurement layout;

(3) Sawing equipment;

(4) Finishing equipment (if any).

4.5 List of main testing equipment, including the technical parameters related to the following equipment:

(1) Universal material testing machine;

(2) Bend testing machine;

(3) Metallographic microscope (if any);

(4) Dimensional inspection equipment;

(5) Non-destructive testing equipment.

4.6 Type test program

4.7 Production process and inspection data: the manufacturing process flow chart of welded plates from the incoming verification of raw materials to the warehousing of finished products, including the main processes and corresponding inspection points; Main process documents and inspection/ test instructions.

4.8 Maintenance and calibration regulations or procedures for welding equipment and its tools.

4.9 Management regulations or related descriptions of purchased blanks.

4.10 Samples of product quality certificates.

5 Technical Requirements

5.1 Requirements for welding equipment and tools

Welding equipment, such as welding machines and FSW tools, shall have the capability to produce the specified standard welds. Instruments, measuring tools, etc. installed on automatic, mechanized or robotic welding equipment shall be calibrated according to preset procedures, and the manufacturer shall develop and record applicable calibration procedures. The required calibration shall also be conducted when instruments and dials have been repaired or replaced. The service life, cleaning and inspection frequency of any friction stir welding tool used in production shall be documented.

5.2 The welded joint shall be cleaned, and the surface that may affect the welding quality (such as parent metal, tools and fixtures) shall be kept free of surface oxides by removing protective oil, grease, dirt or any other contaminants (see Appendix E) within 24 hours before welding. At the same time, the manufacturer can also assess the impact of environmental conditions and timely adjust the cleaning time before welding (no more than 24 hours before welding). Chemical cleaning methods (e.g., alkaline cleaning, solvent wiping, or acid pickling) or mechanical cleaning methods (e.g., wire brushing, scraping, sandblasting, or machining) shall be used as necessary to ensure compliance with the above requirements.

5.3 All flash, misalignment, or other protruding metal shall be removed from the edges of welds after visual inspection. However, the defect removal method shall maintain the thicknesses of welds and parent metal within the tolerance range on drawings, without degrading the properties of weld joints or parent metal.

5.4 The qualifications of welders (welding operators) performing FSW operations shall generally meet the requirements of 4.1.1.5, Chapter 4, Part 3 of Rules for Materials and Welding of the Society, while the qualifications of welders (welding operators) tested according to national or international standards shall meet the requirements of 4.12.4, Chapter 4, Part 3 of Rules for Materials and Welding.

5.5 Repairs to friction stir welds shall be subject to the approved welding procedure, with all operations meeting the applicable requirements, and relevant repair information recorded, including but not limited to:

(1) Number of repairs;

(2) Traceability information of repair locations and related products;

(3) Details of operations (including post-repair inspections) involved in repair.

5.6 Preparation of welding procedure specification (WPS). The manufacturer shall prepare a WPS. WPS shall provide all information required for welding. The minimum information required in WPS is as shown in points 1-10 below. See Appendix C for an example of recommended WPS form.

(1) Manufacturer information;

① Manufacturer's name and address;

② WPQR number that supports WPS.

(2) Parent metal;

① Product form (such as rolled plates, extruded plates and profiles);

② Material designation;

③ Alloy temper (T4, T5, T6, etc.);

④ Maximum thickness of parent metal at joint;

⑤ Backing material.

(3) Equipment identification;

① Model;

② Equipment No.;

③ Equipment manufacturer.

(4) FSW tool information: drawing number, serial number, model, material, size and shape,etc.;

(5) Joint information;

① Welded joint type;

② Welded joint design and dimensional tolerance sketch;

③ Joint gap tolerance;

④ Maximum allowable angular deviation for butt joint.

(6) Preweld cleaning;

(7) Welding details;

① FSW tool rotation parameters (for example, clockwise or counterclockwise rotation, rotation speed);

② Welding sequence and direction on sketch, if applicable;

③ Tilt angle;

④ Side tilt angle;

⑤ Dwell Time;

⑥ Main control methods: force control, position control;

⑦ Axial force;

⑧ Number and direction of beads (if applicable).

(8) Travel speed;

(9) Preheating temperature (if applicable);

(10) Post weld heat treatment: Solution heat treatment, natural and artificial aging, stress relief (method to eliminate the stress caused by correcting deformation and straightening deformed parts).

6 Raw Materials and components

Raw materials for friction stir welded stiffened panels: extruded profiles/plates shall be produced by aluminum alloy plate/profile manufacturers approved by the Society, and provided with product certificates or equivalent documents issued by the Society.

7 Type Test

The type test of friction stir welded aluminum alloy stiffened panel shall be subject to the welding procedure qualification requirements, and the test program can be prepared according to the WPS elements. For the initial approval, the welding procedure qualification can be conducted on a selected typical full-length product; alternatively, a test plate may be welded separately, but in this case, a typical full-length product also must be welded and subject to the preweld inspection, postweld visual and dimensional inspection, and postweld non-destructive testing within its length as required by this Guidelines.

7.1 Typical sample selection principles

The properties, characteristics and manufacturing quality of friction stir welded aluminum alloy stiffened panels for works approval tests shall represent or cover the boundary conditions of the product attributes for which the manufacturer applies for approval: alloy designation, alloy temper, thickness range, and maximum length. Different alloy designations cannot be covered; the alloy temper with low strength can be covered by that with high strength; the approved thickness range shall be in line with the maximum thickness supported by WPS; and the maximum welding length shall meet the maximum capacity of the welding machine of the manufacturer. During approval, the product with a weld as long as possible shall be selected as a typical product for the capacity verification.

7.2 Type test items

(1) Preweld inspection;

(2) Welding procedure qualification test;

(3) Postweld visual and dimensional inspection;

(4) Postweld non-destructive testing.

7.3 Test requirements

7.3.1 Preweld inspection: the parent metal information shall be inspected before welding, such as: whether the size, joint thickness, gap, preweld cleaning, FSW tool parameters, welding equipment parameter settings, etc. meet the requirements of drawings and WPS.

7.3.2 Welding procedure qualification

(1) The implementation of parameters in the welding process shall be checked for the compliance with the requirements of PWPS, such as: FSW tool rotation parameters (for example, clockwise or counterclockwise rotation, rotation speed), welding sequence and direction, tilt angle, side tilt angle, dwell time, main control parameters (force, position), etc.

(2) Weld appearance inspection

The welded test piece/test plate shall be visually inspected according to the requirements of ISO1 17637 or GB/T 32259. Unless otherwise specified in the approved drawings, the acceptance criteria for appearance defects shall generally meet the requirements of Table 7.3.2(2).

Weld Appearance Quality Requirements Table 7.3.2(2)

Defect type	Acceptance criteria
Incomplete fusion and penetration	Not allowed
Surface void and furrow	Not allowed
Toe flash	Meet the design technical requirements
Subsidence	Not allowed, can be removed by grinding
Linear misalignment	h≤0.2t or 2mm, whichever is smaller
Angular deviation	h≤3° or meet the design technical requirements
Surface pit (Incompletely filled groove)	For t≥2mm, h≤0.2mm+0.1t For t<2mm, h≤0.15mm Within any 100mm length range, the total pit length shall not exceed 1/3 of the length and cannot exceed the negative deviation of the parent metal thickness
Uneven weld width	Meet the design technical requirements
Surface irregularity	Meet the design technical requirements

(3) Welding test plates/test pieces shall be subject to surface and internal non-destructive testing.

The acceptance criteria for non-destructive testing of welds may be based on the levels in recognized standards in Table 7.3.2(3) or higher, and other non-destructive testing standards or methods may be used with the consent of CCS. For non-destructive testing of internal defects in welds, either RT or UT can be selected (as the case may be).

Non-destructive Testing Requirements for Welds Table 7.3.2(3)

Method	Standard	Acceptance criteria
PT	ISO 23277	2X
RT	CB/T 3929 NB/T 47013.2	Level II or design technical requirements
UT	NB/T 47013.3 JIS Z3080	NB/T 47013.3: Level II JIS Z3080: Level III or design technical requirements

(4) Mechanical property test

The transverse tensile and bend tests shall be conducted on the head, middle and tail sections of welded test plates/test pieces. The spacing between the sections shall be at least 150mm, and each section shall be provided with one transverse tensile test piece and two bend test pieces (face ×1 and root ×1. For materials with a thickness of more than 12mm, two transverse side bend test pieces can be used in place of one face bend test piece and one root bend test piece), i.e., a total of 3 transverse tensile test pieces and 6 bend test pieces. The results of transverse tensile and bend tests shall comply with the requirements of Section 6, Chapter 8, Part 1 of Rules for Materials and Welding of the Society.

(5) Macro examination

The macro examination shall be conducted on the head, middle and tail sections of welded test plates/test pieces. The spacing between the sections shall be at least 150mm, and the macro examination shall inspect the weld cross-section under a 10X magnifying glass. In addition to the applicable requirements in Table 7.3.2(2), internal defects in welds shall comply with the requirements of Table 7.3.2(5).

Weld Defect Quality Requirements Table 7.3.2(5)

<table>
<tr><th>Defect type</th><th colspan="2">Acceptance criteria</th></tr>
<tr><td>Channel defect</td><td colspan="2">Defect height h≤0.2×weld thickness (T) or 4mm, whichever is smaller.</td></tr>
<tr><td>Incomplete penetration</td><td colspan="2">Not allowed</td></tr>
<tr><td rowspan="2">Root defect
(Welded joint residue)</td><td>Bonded</td><td>Unbonded</td></tr>
<tr><td>Meet the design technical requirements</td><td>Not allowed</td></tr>
<tr><td>Solid inclusion</td><td colspan="2">Multiple inclusions in the same section, l=l 1 +l 2 +……
Inclusions <0.2mm can be ignored, l≤0.2T, T: joint thickness</td></tr>
</table>

(6) Additional tests required in other technical specifications, such as corrosion test (such as for environments in contact with seawater) and metallographic test.

7.3.3 Postweld visual and dimensional inspection

The requirements of drawing documents and Article 7.3.2(2) of this Guidelines shall be met.

7.3.4 Postweld non-destructive testing

The requirements of 7.3.2(3) of this Guidelines shall be met, with welds (at least 300 mm) taken from the head, middle, and tail sections of the product for the surface and internal nondestructive testing.

7.4 In the case of any important variable in welding procedure qualification exceeding the required

range, the procedure qualification shall be re-conducted.

Range of Important Parameter Variables in Welding Procedure Qualification Table 7.4

Parameter	Range subject to re-qualification
Designation	Change of alloy designation
Alloy temper	Change of the same alloy designation from low strength temper to high strength temper
Thickness	Change ±10% or 1mm, whichever is greater
Joint gap	Change of more than 1mm
Tilt angle	Out of range specified in WPS
Side tilt angle	Out of range specified in WPS
Parent metal cleaning	Changes of cleaning method, such as mechanical or chemical method
Spindle speed	Change of more than ±5%
Axial force	Change of more than ±10%
Plunge depth	Change of more than ±10%
Travel speed	Change of more than ±5%
FSW tool	Material change of FSW tool and probe; Structure change of FSW tool and probe, such as: shoulder diameter, probe diameter, probe length, probe shape, threaded or unthreaded; Model change of FSW tool
Dwell time	Change of ±5%
Process control method	Change of force control or position control or vice versa
Preheating temperature	30℃ below the maximum qualification temperature
Post weld heat treatment	Whether post weld heat treatment is conducted

7.5 Retest

If the test piece fails to meet the visual inspection and nondestructive testing requirements specified for the type test items, a new test piece shall be welded according to the original conditions for the same tests. If the newly welded test piece still fails to meet the requirements, the type test will fail.

If the test piece fails the mechanical property test, double test pieces shall be taken for retesting for each non-conformance. These test pieces shall be taken from the corresponding positions of the original test pieces, and subject to the same tests as the original unqualified test pieces. If any one of the test pieces fails to meet the requirements, the type test will fail.

If the type test fails, the causes shall be carefully analyzed, and new test plates shall be welded for all tests after the parameter adjustment.

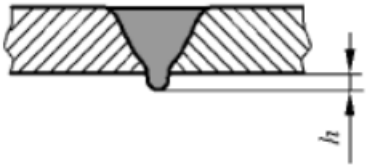
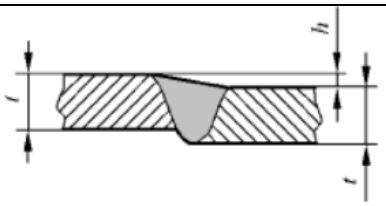
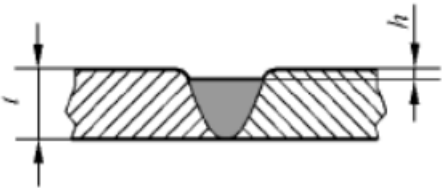
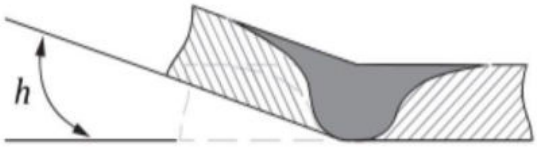
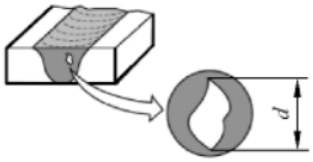
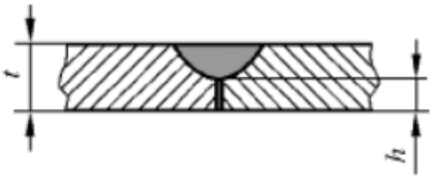
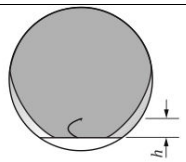
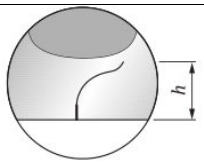
8 Unit/Batch Inspection

The factory inspection items for friction stir welded aluminum alloy stiffened panel are shown in Table 8.

Factory Inspection Items for FSW Aluminum Alloy Stiffened Panel Table 8

Test item	Test requirement	Remarks
Visual inspection	Test results shall meet the design technical requirements and Article 7.3.2(2) of this Guidelines	
Dimensional inspection		
Tensile test	Batch sampling provisions and test results shall meet the requirements of Section 6, Chapter 8, Part 1 of Rules for Materials and Welding	
Bend test		
Non-destructive testing	Test results shall meet the technical document requirements or Article 7.3.2(3) of this Guidelines	When required by the technical document or deemed necessary by the Surveyor
Macro examination	Test results shall meet Article 7.3.2(5) of this Guidelines	Batch sampling provisions shall meet the requirements of Section 6, Chapter 8, Part 1 of Rules for Materials and Welding

Appendix A Schematic Diagram of Weld Defects

Defect name	Schematic diagram
Surface defect	
Subsidence	
Toe flash	
Linear misalignment	
Surface pit	
Angular deviation	
Internal defect	
Cavity	
Incomplete penetration	
Root defect (welded joint residue) bonded	
Root defect (welded joint residue) unbonded	

Appendix B Recommended Preliminary Welding Procedure Qualification Form

Preliminary Welding Procedure Specification（PWPS）

Name and serial number	
Qualified supporting WPQR(S):	
Manufacture's name and address	
Friction stir welding method	Test joint details (sketch with dimensions) Bead sequence details (sketch)
Joint type	
One side ☐ Double side ☐	
Parent metal temper/Specification	
Thickness	Backing material
Preweld cleaning	Post weld heat treatment
Preheating	Preheat method
Welding equipment：	Weld tool drawing number
Process control method: Position control ☐ Force control ☐	
Other information*	
Welding parameters	
Axial Force ([kn])/Plunge depth (mm):	Spindle speed (r/min)：
Direction of tool rotation:	Tilt angle (degrees)
Side tilt angle (degrees)	Travel speed (mm/min)
Dwell time (s)	Joint gap (mm):

Test items and results

1. Non-destructive examination			
Visual ☐	Radiography ☐	Ultrasonic ☐	Liquid penetrate ☐
2. Destructive examination			
Tensile tests ☐			

Bend tests	Face ☐	Root ☐	Side ☐
3. Macro examination ☐			
4. Additional test(s)	Metallograph of the joint（×100） ☐		
	Corrosion test ☐		
	Others ☐		

Note: *If required

☒ Applicable ☐ Not applicable

Signature

Manufacturer _____ Date _____

The following is to be filled in by the Surveyor:

The above-mentioned PWPS has been reviewed and implementation of WPT in accordance with this PWPS is approved. ……☐
The above-mentioned PWPS has been reviewed with comments as follows: (Please reply and contact the attending Surveyor as soon as possible) …… …… …☐

Signature

CCS Surveyor_____ Date _____

Appendix C Recommended Welding Procedure Qualification Form

Welding Procedure Specification（WPS）

Name and serial number	
Qualified supporting WPQR(S):	
Manufacture's name and address	
Base material range	
Friction stir welding method	Test joint details (sketch with dimensions)
Joint type	
One side ☐ Double side ☐	Bead sequence details(sketch)
Parent metal temper/Specification	
Thickness	Backing material
Preweld cleaning	Post weld heat treatment
Preheating	Preheat method
Welding equipment:	Weld tool drawing number
Process control method: Position control ☐ Force control ☐	
Other information*	
Welding parameters	
Axial force ([kn])/Plunge depth(mm):	Spindle speed (r/min):
Direction of tool rotation:	Tilt angle (degrees)
Side Tilt angle (degrees)	Travel speed (mm/min)
Dwell time(s)	Joint gap (mm):

Note: *If required

☒ Applicable ☐ Not applicable

Signature

Manufacturer _____ Date _____

CCS Surveyor _____ Date _____

Appendix D Recommended Welding Procedure Record

Welding Procedure Qualification Record

<table>
<tr><td>Name and serial number</td><td colspan="2"></td></tr>
<tr><td>Manufacture’s name and address</td><td colspan="2"></td></tr>
<tr><td>Base material</td><td colspan="2"></td></tr>
<tr><td>Friction stir welding method</td><td colspan="2" rowspan="3">Test joint details (sketch with dimensions)

Bead sequence details(sketch)</td></tr>
<tr><td>Joint type</td></tr>
<tr><td>One side ☐
Double side ☐</td></tr>
<tr><td colspan="3">Parent metal temper/specification</td></tr>
<tr><td>Thickness</td><td colspan="2">Backing material</td></tr>
<tr><td>Preweld cleaning</td><td colspan="2">Post weld heat treatment</td></tr>
<tr><td>Preheating</td><td colspan="2">Preheat method</td></tr>
<tr><td>Welding equipment：</td><td colspan="2">Weld tool drawing number</td></tr>
<tr><td colspan="3">Process control method: Position control ☐ Force control ☐</td></tr>
<tr><td colspan="3">Other information*</td></tr>
<tr><td colspan="3">Welding details</td></tr>
<tr><td>Axial force ([kn])/Plunge depth(mm)::</td><td colspan="2">Spindle speed (r/min)：</td></tr>
<tr><td>Direction of tool rotation:</td><td colspan="2">Tilt angle (degrees)</td></tr>
<tr><td>Side tilt angle (degrees)</td><td colspan="2">Travel speed (mm/min)</td></tr>
<tr><td>Dwell time(s)</td><td colspan="2">Joint gap (mm):</td></tr>
<tr><td colspan="3">Welder’s name</td></tr>
<tr><td>Humidity:</td><td colspan="2">Temperature :</td></tr>
</table>

Welding Procedure Qualification Record (continued)

Test items and results

1. Non-destructive examination			
Visual ☐	Radiography ☐	Ultrasonic ☐	Liquid penetrate ☐
2. Destructive examination			
Tensile tests			

Test piece	Tensile strength(N/mm^2)	Location of rupture	Test temp.
Transverse			
Transverse			
Transverse			
Transverse			

Bend tests

Test piece	Former / angle	Result	Remarks
Face / Root /Side			
Face / Root /Side			
Face / Root /Side			
Face / Root /Side			
Face / Root /Side			
Face / Root /Side			

Macro examination

Additional test(s) and result(s)

Note: ☒ Applicable ☐ Not applicable

Signature

Manufacturer _____ Date _____

CCS Surveyor _____ Date _____

Appendix

In order to insure the quality of welding procedure test and make it traceable, copies of the documents listed below are to be submitted. (Items in the list may be added or deleted as necessary).

List of Documents

No.	Document name	Page	Remarks
1	Certification of base material		
2	NDT reports		
3	Test source recording (Tensile tests, Bend tests, etc.)		
4	Macro examination reports (Photo and result)		
5	Photos of weld surface		
6	Photos of test pieces		
7	Welder' certificate issued by CCS(if any)		

Appendix E "S" Line in Friction Stir Welding of Aluminum Alloy

The "S" line phenomenon is prone to occur in the process of friction stir welding of aluminum alloy, which is mainly caused by the incomplete removal of oxides and impurities on the joint surface of the weldment during the friction stir welding process, or the crushing of oxides on the joint surface and impurities near the weld by the probe, leading to continuous "S" shaped oxide strips in the process of flowing and forming of weld plasticized metal. The characteristics of "S" line are related to the flow of plasticized metal. Therefore, the factors that affect the flow and formation of the weld metal, such as the shape and size of FSW tool, the direction of tool rotation, and the welding parameters, will significantly affect the characteristics of the "S" line. At the same time, the "S" line is difficult to detect by the non-destructive testing method (RT, UT), and can only be effectively detected by the macro examination.

It is generally believed that the "S" line will not affect the performance of the welded joint, which may be related to the size, density and connectivity of oxide particles constituting the "S" line. The performance of the welded joint can be affected only when the oxide particles gather in the joint to a certain extent under certain conditions, which becomes a potential problem in the actual application of welded structural parts. Therefore, this defect shall be reduced or avoided as much as possible in the welding manufacturing process of the friction stir welded aluminum alloy stiffened panel.