NIPPON STEEL

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Welding of SuperDyma™
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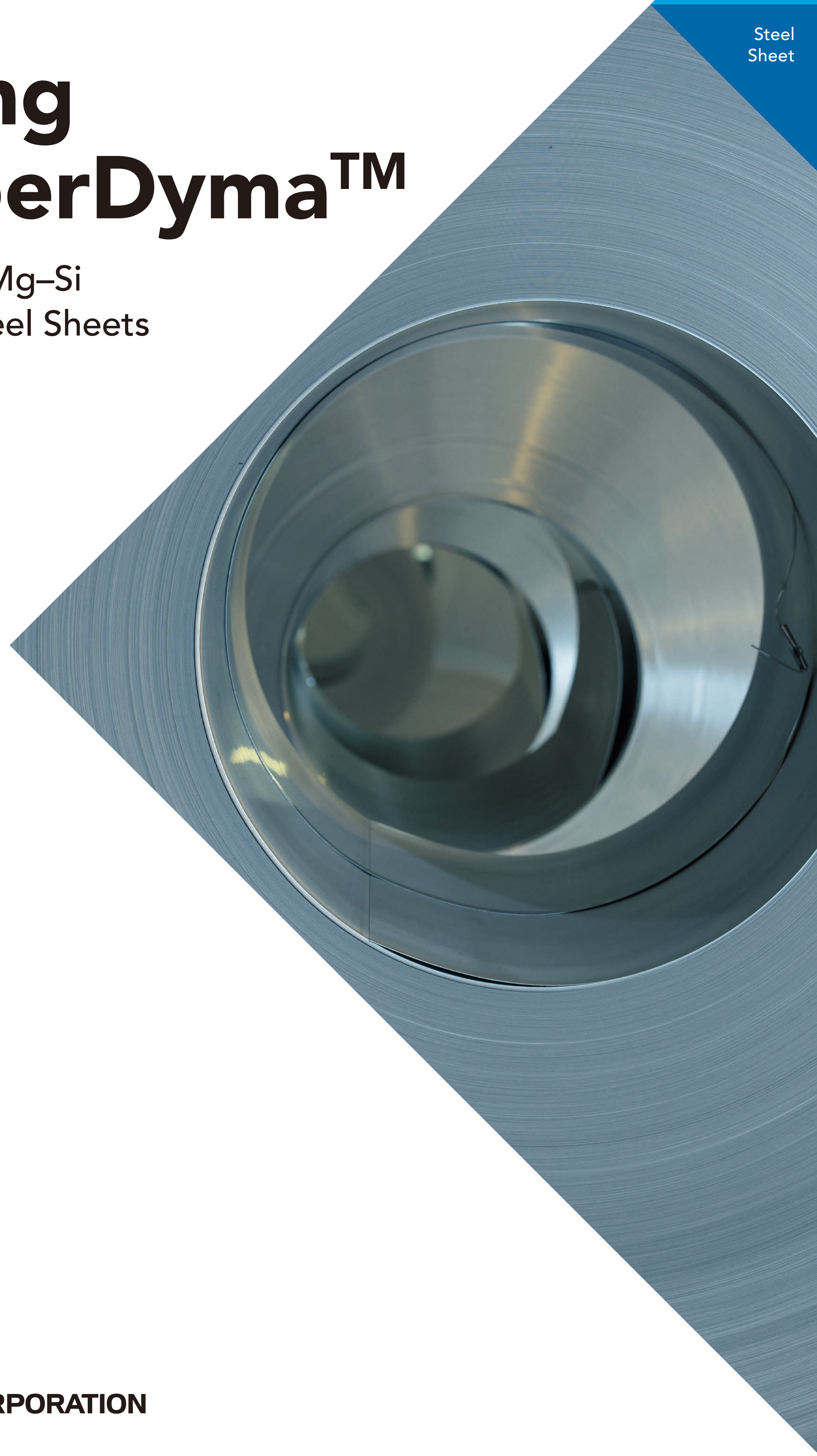
NIPPON STEEL

Steel Sheet

Welding of SuperDyma™

Hot–dip Zn–Al–Mg–Si Alloy Coated Steel Sheets



NIPPON STEEL CORPORATION

Contents

Arc Welding Procedures for SUPERDYMA

1. Scope of Applications

These welding procedures apply to SUPERDYMA of NIPPON STEEL æhot-dip zinc-aluminum-magnesium alloy coated steel sheets for building structures that have plate thicknesses of 0.8 mm to 9.0 mm and coating masses from K06 to K45 in coating mass symbols (hereinafter referred to as "SUPERDYMA").

Regarding coated sheets with coating masses greater than K27, the coating thickness or mass is to be reduced ore removed by the procedures in section 2.4 so that the remaining coating thickness equals K27 or less. Following this, welding can be applied to these sheets.

2. Welding Methods

2.1 Welding Machines

CO_2 gas welding, or MAG, welding machines shall be used as welding machines and shall supply the specified welding power. With regard to welding power sources, inverter and pulse power sources designed to lessen sputtering and prevent burn through are available on the market and are recommended to be used properly as needed.

2.2 Welding Wires and Shield Gases

The welding wire prescribed in JIS Z 3312 or Z 3313 shall be used as welding wire.

With regard to shield gas, either liquefied CO_2 gas as prescribed in Type 3, JIS K 1106, or the mixture of liquefied CO_2 gas and argon gas as prescribed in Class 1, JIS K 1105 shall be used. In addition, mixtures containing oxygen and other gases may be used when the quality of the welds is confirmed.

Table 1 shows the standard conditions for welding wire and shield gases used in the welding of coated sheets.

Table 1 Standard Conditions for Welding Wires and Shield Gases

Kind of wire	Use	Shield gas
JIS Z 3312 YGW14 equivalents	For galvanized steel sheet by means of CO_2 gas arc welding	CO_2 gas
JIS Z 3312 YGW17 equivalents	For galvanized steel sheet by means of MAG welding	80% argon gas + 20% CO_2 gas

2.3 Welding

As regards welding position, flat welding shall be applied whenever possible by means of positioners etc. In cases where welding in other positions is unavoidable, such as during on-site welding and when handling large structures, welding should be conducted under stabile conditions in terms of both worksite and safety. Further, in the welding of steel sheets, because deviations in welding conditions are apt to result in inferior weld penetration and burn through, the adoption of robotic welding or other automatic welding methods is recommended.

In Fig. 1, a butt-weld joint and a lap fillet weld joint are shown as commonly-used weld joints.

Fig. 1 Standard Welding Positions

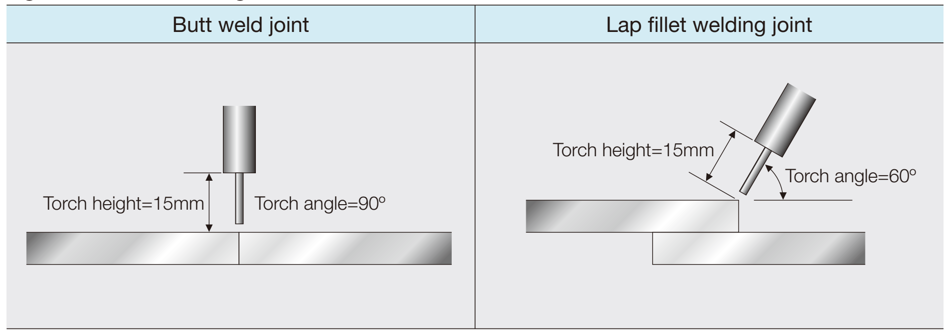


Table 2 Standard Welding Conditions for Butt Weld Joints in CO_2 Gas Arc Welding

	Thickness (mm)	0.8	1.2	1.6	2.3	3.2	4.5		6.0		9.0		
Groove conditions	Backing metal	No use	No use	No use	No use	No use	use		use		use		
	Gap between steel sheets (mm)	≦0.3	≦0.3	≦0.3	≦0.3	≦0.3	4		4		4		
Welding conditions	Shield gas flow amount (L/min)	30	30	30	30	30	30		30		30		
	Torch height (mm)	15	15	15	15	15	15		15		15		
	Welding wire diameter(mm)	ϕ0.8	ϕ1.2	ϕ1.2	ϕ1.2	ϕ1.2	ϕ1.2		ϕ1.2		ϕ1.2		
	No. of passes	1	1	1	1	1	1	2	1	2	1	2	3
	Welding current (A)	45~55	80~90	110~120	140~150	170~180	210~230	210~230	230~250	260~280	230~250	260~280	270~290
	Arc voltage (V)	18~19	19~20	21~23	22~24	21~24	21~24	21~24	22~25	25~28	22~25	25~28	28~30
	Welding speed (cm/min)	80~90	70~80	70~80	50~60	50~60	40~50	40~50	30~40	30~40	30~40	30~40	30~40

Table 3 Standard Welding Conditions for Lap Fillet Weld Joints in CO_2 Gas Arc Welding

	Thickness (mm)	0.8	1.2	1.6	2.3	3.2	4.5	6.0	9.0
Groove conditions	Knuckle of steel sheets (º)	≦2	≦2	≦2	≦2	≦2	≦2	≦2	≦2
	Gap between steel sheets (mm)	≦0.3	≦0.3	≦0.3	≦0.3	≦0.3	≦0.3	≦0.3	≦0.3
Welding conditions	Shield gas flow amount (L/min)	30	30	30	30	30	30	30	30
	Torch height (mm)	15	15	15	15	15	15	15	15
	Welding wire diameter (mm)	ϕ1.2	ϕ1.2	ϕ1.2	ϕ1.2	ϕ1.2	ϕ1.2	ϕ1.2	ϕ1.2
	No. of passes	1	1	1	1	1	1	1	1
	Welding current (A)	65~75	80~90	100~110	150~160	170~180	240~270	280~310	310~330
	Arc voltage (V)	18~19	19~20	20~22	20~22	20~23	24~27	27~30	30~33
	Welding speed (cm/min)	60~70	50~60	40~50	40~50	40~50	40~50	40~50	30~40

2.4 Treatment of Coating

In cases when the coating mass is greater than K27 in coating mass symbol, welding will be conducted after carrying out acid-pickling removal or mechanical grinding in conformity with the procedures shown in Table 4.

Table 4 Procedures to Reduce or Remove Coating Layers in Case of Welding Coated Sheets with Coating Mass Symbols Greater Than K27

Item	Treatment
Thickness of remaining coating layer	Thickness equivalent to K27 or under
Range for reduction and removal of coating layer	Range of weld bead width and 5 mm or more from both sides of bead width

Assessment Test Results for Arc Weldability of SUPERDYMA

In order to assess the arc weldability of SUPERDYMA, tension tests and sectional macroscopic observations were conducted primarily on coated sheets with a heavy coating mass and thin plate thickness to confirm that they demonstrate good weld joint performance. The applied welding method was the commonly-used CO_2 gas arc welding. A detailed assessment is introduced below.

1. Test Specimens

1.1 Coated Sheets

Table 5 shows the coated sheets applied in welding. The test specimens consisted of steel sheets with a specified tensile strength of 400 N/mm^2 and various thicknesses; both sides of the specimens were coated with the coating masses shown in Table 5.

Table 5 List of Test Specimens

Thickness (mm)	Coating mass symbol	Chemical composition (%)					Mechanical properties			Coating mass (g/m^2)
		C	Si	Mn	P	S	Yield point (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)	
0.8	K27	0.170	0.013	0.47	0.014	0.0105	340	491	32.0	322
1.2	K27	0.168	0.011	0.47	0.013	0.0138	297	457	34.0	313
1.6	K27	0.167	0.010	0.47	0.016	0.0069	302	455	37.0	283
3.2	K27	0.160	0.012	0.49	0.012	0.0080	363	484	33.0	340
9.0	K14	0.090	0.006	0.56	0.012	0.0050	300	408	42.0	173

1.2 Welding Materials

Table 6 shows the welding materials used in welding.

Table 6 Welding Wires and Shield Gases

Kind of welding wire	Use	Shield gas	Example of mechanical properties of weld metal		
			Yield point (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)
JIS Z 3312 YGW14 equivalents	For hot-dip galvanized steel sheets by means of CO_2 gas arc welding	CO_2 gas	460	600	32

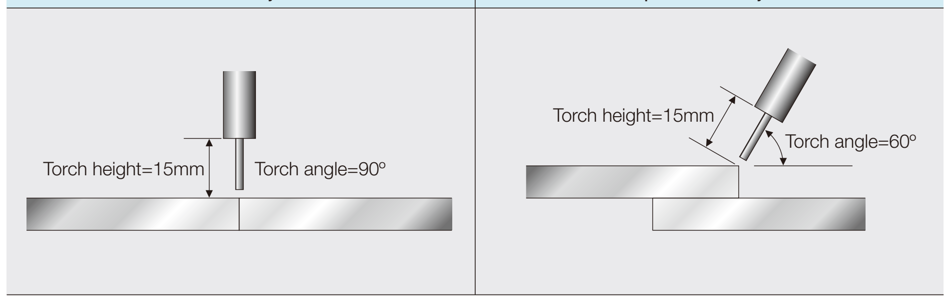
2. Welding Conditions

2.1 Weld Joints

Butt welding and lap fillet welding were conducted. Fig. 2 shows the welding positions.

Fig. 2 Welding Positions

Butt weld joint | Lap fillet weld joint



2.2 Welding Conditions

Table 7 shows the welding conditions for butt welding, and Table 8 shows those for lap fillet welding.

Welding conditions were determined so that butt-welded joints would achieve fully penetrated welding and lap fillet weld joints would have leg lengths equal to plate thickness on the upper sheet side and thicker than plate thickness on the lower sheet side. When welding coated sheets, in contrast to the welding of uncoated sheets, it is necessary to use weld arc heat to evaporate and remove the coated metal. For this reason, in particularly welding coated sheets 1.2 mm or under in plate thickness, the welding conditions were set for the welding current and the arc voltage to a comparatively higher level. Further, in cases of high welding speed where blow hole defects are likely to occur, the welding conditions were set for comparatively low welding speeds. An inverter-type direct current power source was used as the welding power source.

Table 7 Welding Conditions for Butt Weld Joints

	Thickness (mm)	0.8	1.2	1.6	3.2	9.0		
Groove conditions	Backing metal	No use	No use	No use	No use	Use		
	Gap between steel sheets (mm)	≦0.3	≦0.3	≦0.3	≦0.3	4		
Welding conditions	Shield gas flow amount (L/min)	30	30	30	30	30		
	Torch height (mm)	15	15	15	15	15		
	Welding wire diameter (mm)	ϕ0.8	ϕ1.2	ϕ1.2	ϕ1.2	ϕ1.2		
	No. of passes	1	1	1	1	1	2	3
	Welding current (A)	50	85	120	180	230	270	270
	Arc voltage (V)	18	19	22	22	22	25	28
	Welding speed (cm/min)	80	80	80	40	40	30	30

Table 8 Welding Conditions for Lap Fillet Weld Joints

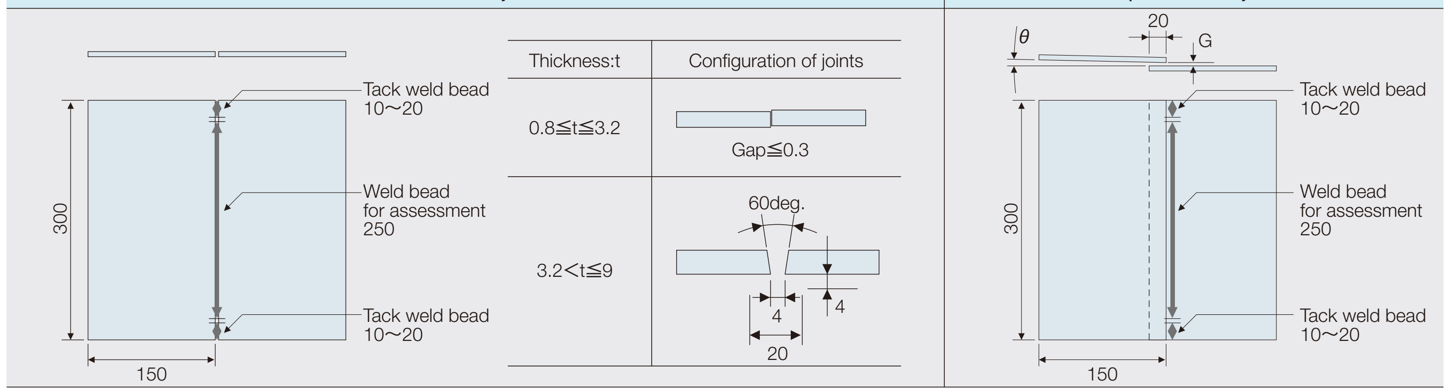
	Thickness (mm)	0.8	1.2	1.6	3.2	9.0
Groove conditions	Groove conditions (°)	≦2	≦2	≦2	≦2	≦2
	Knuckle of steel sheets (mm)	≦0.3	≦0.3	≦0.3	≦0.3	≦0.3
Welding conditions	Shield gas flow amount (L/min)	30	30	30	30	30
	Torch height (mm)	15	15	15	15	15
	Welding wire diameter (mm)	ϕ1.2	ϕ1.2	ϕ1.2	ϕ1.2	ϕ1.2
	No. of passes	1	1	1	1	1
	Welding current (A)	70	90	100	170	330
	Arc voltage (V)	18	20	21	22	32
	Welding speed (cm/min)	60	60	40	40	30

2.3 Configurations and Sizes of Weld Test Specimens

Fig. 3 shows the configuration of the test specimens. Both ends of each specimen were tack-welded to fix the specimen; the center section of the specimen was designated as the weld site for use in the assessment. Meanwhile, taking weld deformation into account, the assembly accuracy of the specimens was set at a knuckle angle (θ)=2° or under and a gap (G) of 0.3 mm or under. In butt welding, backing metal was not used for sheets with thicknesses of 3.2 mm or less and were used only for sheets with thicknesses greater than 3.2 mm.

Fig. 3 Configuration of Weld Test Specimens

(unit: mm)



3. Assessment of Weld Joint Performance

The test specimens used for tension tests and sectional macroscopic observations were extracted from the weld test specimens that were used to assess the welds. Fig. 4 shows the extraction location.

Fig. 4 Test Specimen Extraction Position

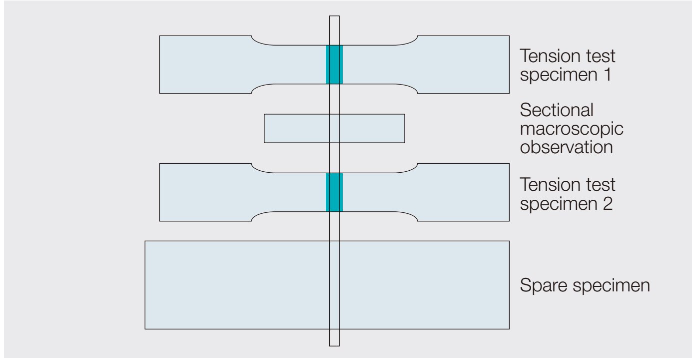
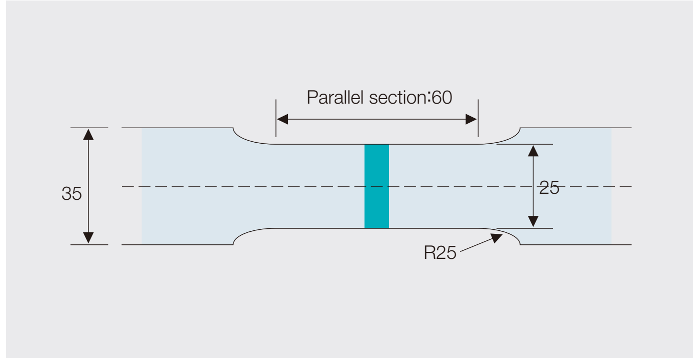


Fig. 5 Configuration of Tension Test Specimens (Distance between gauge marks=50 mm)



3.1 Tension Tests (JIS No. 5 Specimens)

In order to examine the tensile strength of welds, tension tests were conducted on specimens extracted from the weld test specimens. Fig. 5 shows the configuration of the tension test specimens.

The Steel Structure Design Standards (Architectural Institute of Japan; established in 1970 and revised in 1996) prescribe that the unit design stress should be lower than the unit allowable stress for weld joints. In the Standards, the specified unit allowable stress for butt weld and lap fillet weld joints is based on the standard strength of steel products: F value.

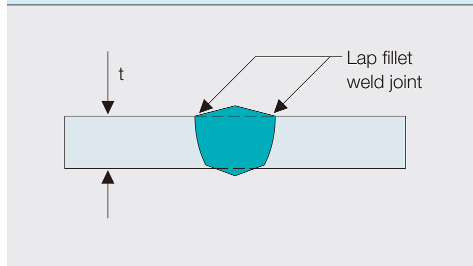
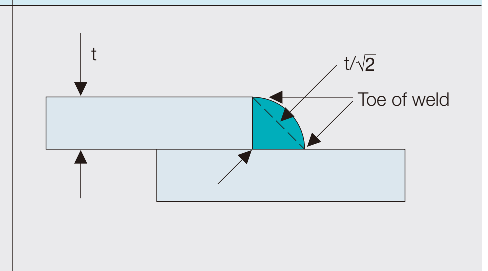
In general, the specified yield point of steel products is used as the F value. But the current assessment was made to grasp the tensile property of weld joints; therefore, the specified tensile strength was defined as the Fm value, which was set as the target value. Table 9 shows the target tensile strength for the tension test conducted in the current assessment.

Table 9 Target Tensile Strength in Tension Tests

Steel grade		Steel products for building structures (thickness: 40 mm or under)
		400(N/mm^2)equivalents
Standard strength of steel products: Fm value		400
Type of joints	Butt weld joint (Fm)	400
	Lap fillet weld joint (Fm/$\sqrt{3}$)	231

Table 10 shows the method to calculate the tensile strength of each tension test specimen. Because the butt weld joints were prepared by full-penetration welding, the values obtained by dividing the breaking load by the width and thickness of the specimens were set as the tensile strength. On the other hand, the fillet weld joints were prepared by partial penetration welding, and the throat thickness was defined as the thickness of welds effectively working as the weld strength. In the design of structures, there are many cases in which plate thickness/$\sqrt{2}$ is adopted as the effective throat thickness. Thereupon, the value obtained by dividing the breaking load by the specimen width and the effective throat thickness (plate thickness/$\sqrt{2}$) was set as the tensile strength of the lap fillet weld joints.

Table 10 Methods to Calculate Tensile Strength

Butt weld joint	Toe of weld
	
σ=P/(W·t)	σ=P/(W·t/$\sqrt{2}$)

σ: Tensile strength P: Fracture load W: Specimen width t: Thickness

Table 11 shows the results of tension tests on butt weld joints, and Table 12 those for lap fillet weld joints. Photos 1 to 5 show the appearance of the specimens after tension testing.

Regardless of the configuration and thickness of the joints, the tensile strength values obtained in all the tension tests met the target tensile strength, and it was confirmed that the strength of the joints was nearly equal to that of the base metal. Further, the fracture position was in most cases located in the base metal. For lap fillet weld joints, there were cases in which the fracture occurred from the toe of weld or heat-affected zone, but it was confirmed that there were no blow holes or other weld defects at the fracture surface. Meanwhile, the tensile strength of the lap fillet weld joints was larger than that of the butt weld joints, but this is attributable to an increase in apparent strength caused by the use of effective throat thickness in calculating tensile strength. When the strength was recalculated by replacing the effective throat thickness with the plate thickness, both lap fillet weld joints and butt weld joints showed nearly the same tensile strength.

Table 11 Tension Test Results for Butt Weld Joints

Symbol	Kind of coating	Thick-ness (mm)	Specified tensile strength (N/mm^2)	Measured tensile strength (N/mm^2)	Fracture position
D1B-1	K27	0.8	400	420	Base metal
D1B-2				422	Base metal
D4B-1	K27	1.2	400	459	Base metal
D4B-2				455	Base metal
D5B-1	K27	1.6	400	466	Base metal
D5B-2				467	Base metal
D7B-1	K27	3.2	400	506	Base metal
D7B-2				504	Base metal
D10B-1	K14	9.0	400	437	Base metal
D10B-2				430	Base metal

Table 12 Tension Test Results for Lap Fillet Weld Joints

Symbol	Kind of coating	Thick-ness (mm)	Specified tensile strength (N/mm^2)	Measured tensile strength (N/mm^2)	Fracture position
D1L-1	K27	0.8	400	596	From heat-affected zone to base metal
D1L-2				595	Base metal
D4L-1	K27	1.2	400	632	From heat-affected zone to base metal
D4L-2				622	From heat-affected zone to base metal
D5L-1	K27	1.6	400	637	Base metal
D5L-2				640	Base metal
D7L-1	K27	3.2	400	685	Toe of weld
D7L-2				678	Toe of weld
D10L-1	K14	9.0	400	557	Toe of weld
D10L-2				572	Toe of weld

Photo 1.1 Fracture Conditions in Tension Tests for Butt Weld Joints (thickness: 0.8 mm)

Symbol	Steel grade	Thickness	Coating mass symbol
D1B	Zn–Aℓ –Mg(400)	0.8mm	K27

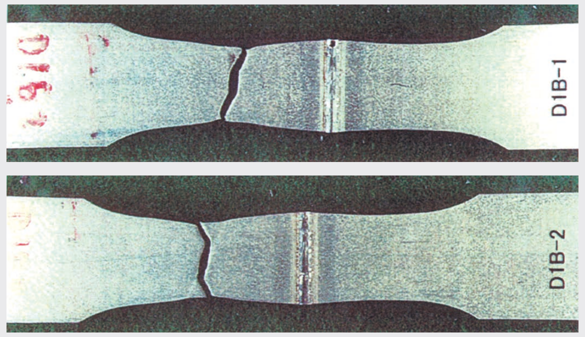


Photo 1.2 Fracture Conditions in Tension Tests for Lap Fillet Weld Joints (thickness: 0.8 mm)

Symbol	Steel grade	Thickness	Coating mass symbol
D1L	Zn–Aℓ –Mg(400)	0.8mm	K27

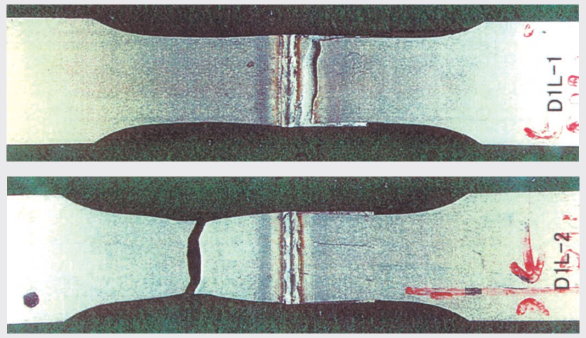


Photo 2.1 Fracture Conditions in Tension Tests for Butt Weld Joints (thickness: 1.2 mm)

Symbol	Steel grade	Thickness	Coating mass symbol
D4B	Zn–Aℓ –Mg	1.2mm	K27

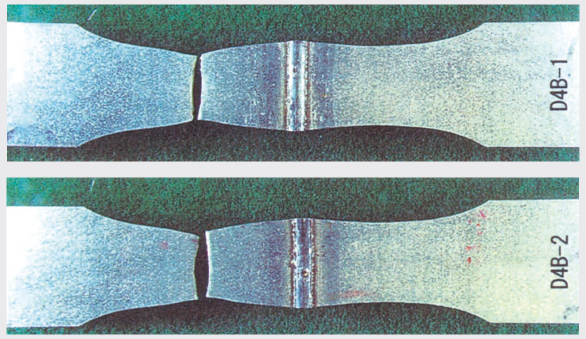


Photo 2.2 Fracture Conditions in Tension Tests for Lap Fillet Weld Joints (thickness: 1.2 mm)

Symbol	Steel grade	Thickness	Coating mass symbol
D4L	Zn–Aℓ–Mg(400)	1.2mm	K27

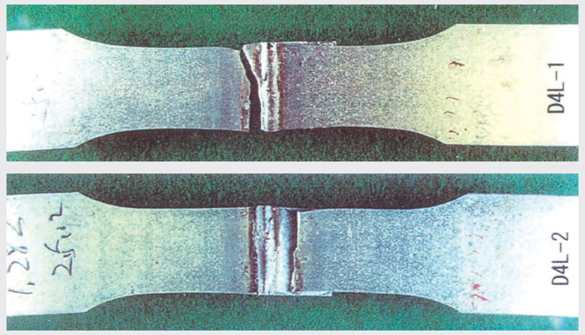


Photo 3.1 Fracture Conditions in Tension Tests for Butt Weld Joints (thickness: 1.6 mm)

Symbol	Steel grade	Thickness	Coating mass symbol
D5B	Zn–Aℓ –Mg(400)	1.6mm	K27

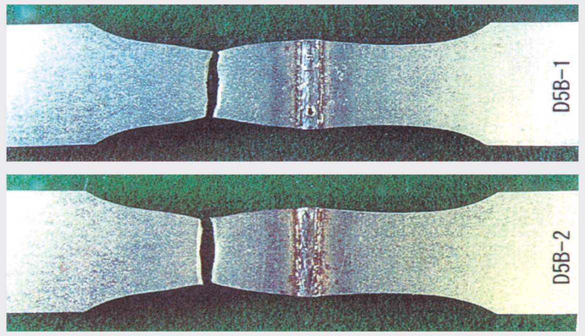


Photo 3.2 Fracture Conditions in Tension Tests for Lap Fillet Weld Joints (thickness: 1.6 mm)

Symbol	Steel grade	Thickness	Coating mass symbol
D5L	Zn–Aℓ –Mg(400)	1.6mm	K27

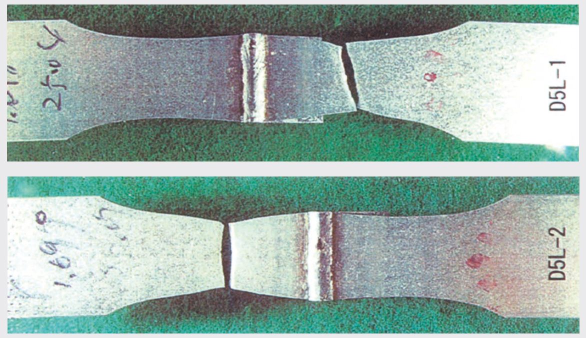


Photo 4.1 Fracture Conditions in Tension Tests for Butt Weld Joints (thickness: 3.2 mm)

Symbol	Steel grade	Thickness	Coating mass symbol
D7B	Zn–AL–Mg(400)	3.2mm	K27

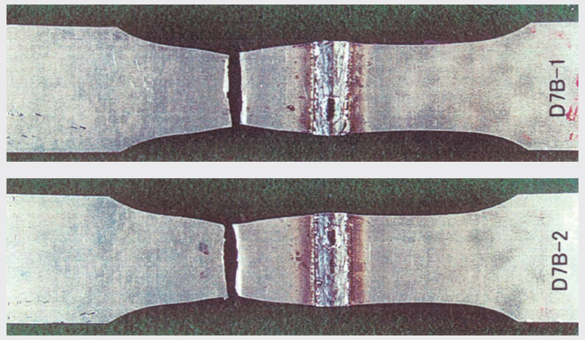


Photo 4.2 Fracture Conditions in Tension Tests for Lap Fillet Weld Joints (thickness: 3.2 mm)

Symbol	Steel grade	Thickness	Coating mass symbol
D7L	Zn–Aℓ –Mg(400)	3.2mm	K27

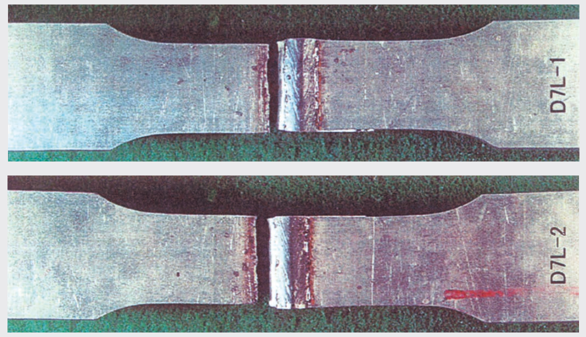


Photo 5.1 Fracture Conditions in Tension Tests for Butt Weld Joints (thickness: 9.0 mm)

Symbol	Steel grade	Thickness	Coating mass symbol
D10B	Zn–Aℓ –Mg(400)	9.0mm	K14

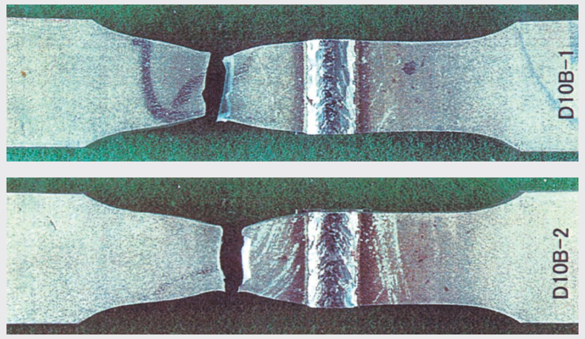
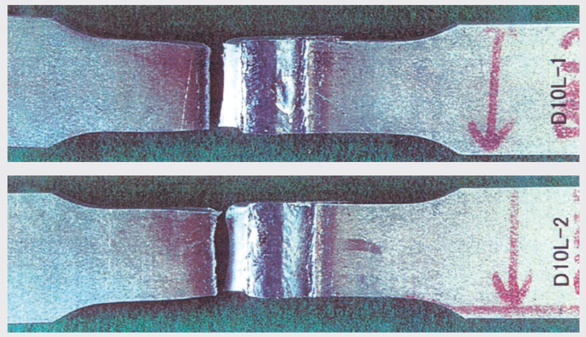


Photo 5.2 Fracture Conditions in Tension Tests for Lap Fillet Weld Joints (thickness: 9.0 mm)

Symbol	Steel grade	Thickness	Coating mass symbol
D10L	Zn–Aℓ –Mg(400)	9.0mm	K14

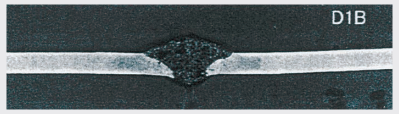
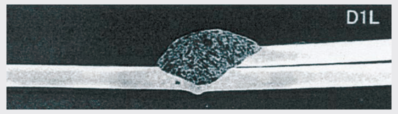
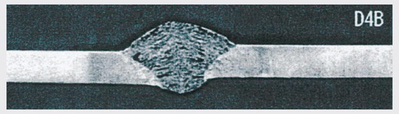
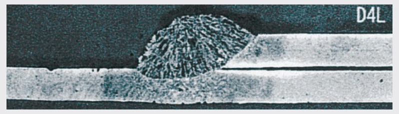
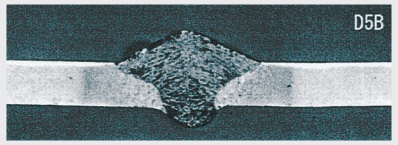
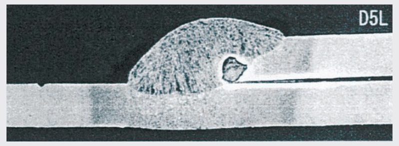
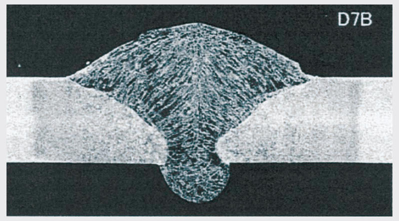
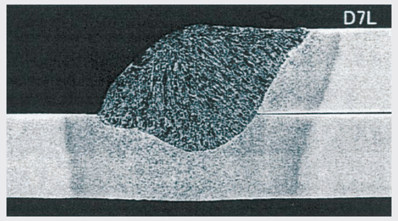
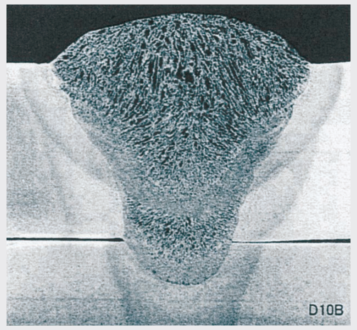
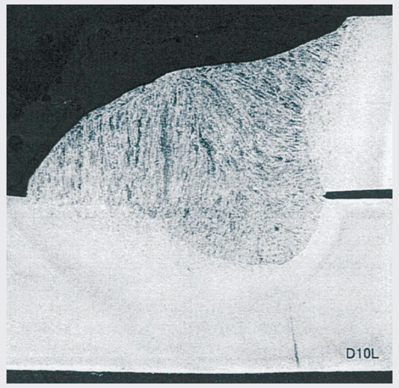


3.2 Sectional Macroscopic Observations

In order to examine the occurrence of blow holes and cracks in welds, sectional macroscopic observations were carried out by means of nital etching.

Photo 6 shows a sectional macroscopic photo of welds. Blow holes caused by coating vapor were not observed during butt welding. During lap fillet welding, on the other hand, there was a slight occurrence of blow holes. However, it was confirmed that good penetration was attained for both types of welds, that there was no occurrence of weld cracks and that good-quality welds were obtained.

Photo 6 Examination Results for Sectional Microstructures of Arc Welds of SUPERDYMA

Thickness (mm)	Coating mass symbol	Sectional microstructure	
		Butt weld joint	Lap fillet weld joint
0.8	K27		
1.2	K27		
1.6	K27		
3.2	K27		
9.0	K14		

3.3 References

Effect of coating layers on welds

When coated sheets are arc-welded, the steel sheet enters a molten state and the coating evaporates or becomes slaggy at the weld. Accordingly, the coating layer is basically excluded from the weld and, thereby, exerts no effect on the weldability of steel sheets.

In lap fillet welding or butt welding using backing metals, there are cases in which blow holes remain in the weld metal. However, it was confirmed that these blow holes do not cause any deterioration in weld joint strength if the welding is performed under appropriate welding conditions.

Spot Welding Procedures for SUPERDYMA

1. Scope of Applications

These welding procedures apply to the spot welding of SUPERDYMA with plate thicknesses from 0.4 mm to 9.0 mm and coating masses from K06 to K45 in coating mass symbols.

Regarding coated sheets with coating masses greater than K27, the coating thickness or mass is to be reduced or removed by the procedure in section 2.4 so that the remaining coating thickness equals K27 or less. Following this, welding can be applied to these sheets.

2. Welding Methods

2.1 Welding Machines

The welding machines to be used shall be of the spot welding type and shall supply the specified welding power.

2.2 Welding Conditions

Fig. 6 shows the standard spot welding method and the configuration of weld joints.

In spot welding, multiple steel sheets are sandwiched between electrodes, electric current is applied to the steel sheets while they are pressurized with electrodes and the sheets are welded by electrical Joule heat.

The strength of spot welds is affected by plate thickness, the strength of the steel product and nugget diameter. In general, as the plate thickness increases, greater weld strength is required; accordingly, it is necessary to increase the nugget diameter. That is, in spot welding the target nugget diameter varies depending on the plate thickness. Table 13 shows the relation between plate thickness (t) and nugget diameter when welding steel sheets with a strength rating of 400 N/mm^2.

Fig. 6 Standard Spot Welding Method and Weld Joint Configuration

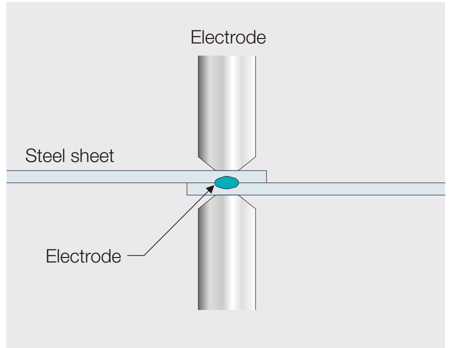


Table 13 Target Nugget Diameters

Thickness (mm)	0.4	0.6	1.0	1.6	2.3	3.2	4.5	6.0	7.5	9.0
Target nugget diameter (mm)	3.2	3.9	5.0	6.3	7.6	8.9	10.6	14.7	16.4	18

For target nugget diameters of t≦4.5 mm in Table 13, those in Table 16 of JIS Z 3140 (Average Value of Class A: Reference Material 1) were adopted. In the standards, the nugget diameter for t≦5 mm is set at $5\sqrt{t}$. However, the values for t>5 mm are derived from JIS, and the strength of welds conforming to this plate thickness cannot be secured by using the JIS target nugget diameters. Therefore, the target nugget diameter was newly set at $6\sqrt{t}$.

In spot welding, while this target nugget diameter is secured, it is recommended to restrict strong expulsion and cracking inside the nugget to a minimum. Several welding conditions that satisfy these requirements are conceivable, but the welding conditions shown in Table 14 are established as standard for the spot welding of SUPERDYMA.

Table 14 Standard Conditions for Spot Welding

Steel sheet		Thickness (mm)					
		0.4	2.3	3.2	6.0	7.5	9.0
Spot welding machine		1ϕAC、60kVA	1ϕAC、150kVA	1ϕAC、150kVA	1ϕAC、150kVA	1ϕAC、150kVA	1ϕAC、150kVA
Electrode (mm)	Outside diameter(D)	ϕ16	ϕ25	ϕ25	ϕ25	ϕ25	ϕ25
	Top configuration	CR(R40)	CR(R75)	CR(R75)	CR(R75)	CR(R75)	CR(R75)
	Size	ϕ3.5	ϕ8	ϕ11	ϕ15	ϕ16	ϕ18
Welding pressure (kN)		1	5.7	8	15	19	22
Welding time (cyc.) 50Hz	Sq.T	20	30	30	40	40	40
	W.T	6	35	65	20-5(6N)	20-5(8N)	20-5(9N)
	Ho.T	6	25	35	60	75	90
Welding current (kA)		7.0~8.5	12.0~14.5	14.0~16.5	21.0~26.0	25.0~30.5	29.0~35.0

*Performance of weld machine timer : Maximum time setting=99 cycles; Maximum pulsation number=10
20-5 (6N) in pulsation welding: 20c (electricity application)-5c (cooling)-6 cycles

2.3 Multi-spot Welding

The center distance between spots is based on JIS Z 3136 for t≦5 mm, on which welding is performed. Because JIS does not prescribe the center distance for 5 mm<t≦9.0 mm, the plate width (W) adopted in JIS for thicknesses from 2.5 mm or more to 5.0 mm shall be applied as the practical distance between spots.

2.4 Treatment of Coating

In cases when the coating mass is greater than K27 in coating mass symbol, welding is conducted after acid-pickling removal or mechanical grinding of the coating layer in conformity with the procedures shown in Table 15.

Table 15 Procedures to Reduce or Remove Coating Layers when Welding Coated Sheets with Coating Mass Symbols Greater Than K27

Item	Treatment
Thickness of remaining coating layer	Thickness equivalent to K27 or under
Range for reduction and removal of coating layer	Range of 30 mm or more in diameter, including the weld and its peripheral area

Reference Materials 1 Target Nugget Diameters in Spot Welding

JIS Z 3140: Inspection Method for Spot Welding

Table 16 Nugget Diameters (Steel) (unit: mm)

Thickness	A, AF classes		B, BF classes		C, CF classes	
	Min.	Average	Min.	Average	Min.	Average
0.4	2.7	3.2	2.4	2.8	1.9	2.2
0.5	3.0	3.5	2.7	3.2	2.1	2.5
0.6	3.3	3.9	3.0	3.5	2.3	2.7
0.7	3.6	4.2	3.2	3.8	2.5	2.9
0.8	3.8	4.5	3.4	4.0	2.7	3.1
0.9	4.0	4.7	3.6	4.3	2.8	3.3
1.0	4.3	5.0	3.8	4.5	3.0	3.5
1.2	4.7	5.5	4.2	4.9	3.3	3.8
1.4	5.0	5.9	4.5	5.3	3.5	4.1
1.5	5.2	6.1	4.7	5.5	3.6	4.3
1.6	5.4	6.3	4.8	5.7	3.8	4.4
1.8	5.7	6.7	5.1	6.0	4.0	4.7
2.0	6.0	7.1	5.4	6.4	4.2	5.0
2.3	6.4	7.6	5.8	6.8	4.5	5.3
2.5	6.7	7.9	6.0	7.1	4.7	5.5
2.6	6.9	8.1	6.2	7.3	4.8	5.6
2.8	7.1	8.4	6.4	7.5	5.0	5.9
3.0	7.4	8.7	6.6	7.8	5.2	6.1
3.2	7.6	8.9	6.8	8.0	5.3	6.3
3.6	8.1	9.5	7.3	8.5	5.6	6.6
3.8	8.3	9.7	7.5	8.8	5.8	6.8
4.0	8.5	10.0	7.7	9.0	6.0	7.0
4.5	9.0	10.6	8.1	9.5	6.3	7.4
5.0	9.5	11.2	8.6	10.1	6.7	7.8

Assessment Test Results for Spot Weldability of SUPERDYMA

In order to assess the spot weldability of SUPERDYMA, tension tests and sectional macroscopic observations were conducted centering on coated sheets with a heavy coating mass and thin plate thickness to confirm that these sheets have good weld joint performance. Detailed assessment methods are introduced below.

1. Test Specimens

Coated Sheets

The coated sheets used in welding conform to Table 17. Steel sheets with a specified tensile strength of 400 N/mm² and various thicknesses were used as test specimens; the coating masses of these sheets were as shown in Table 17.

Table 17 List of Test Specimens

Thickness (mm)	Coating mass symbol	Chemical composition(%)					Mechanical properties			Coating mass (g/m²)
		C	Si	Mn	P	S	Yield point (N/mm²)	Tensile strength (N/mm²)	Elongation (%)	
0.4	K27	0.047	0.013	0.18	0.023	0.012	321	435	30.0	328
3.2	K27	0.160	0.012	0.49	0.012	0.008	363	484	33.0	340
9.0	K14	0.090	0.006	0.56	0.012	0.005	300	408	42.0	173

2. Welding Methods

2.1 Spot Welding Conditions

Spot welding was conducted under the conditions shown in Table 18.

Table 18 List of Welding Conditions

Steel sheet		Thickness (mm)		
		0.4	3.2	9.0
Test specimen size (mm)		Conforming to Table 19	Conforming to Table 19	Conforming to Table 19
Spot welding machine		1 φ AC､60kVA	1 φ AC､150kVA	1 φ AC､150kVA
Electrode (mm)	Outside diameter (D)	φ 16	φ 25	φ 25
	Top configuration	CR (R40)	CR (R75)	CR (R75)
	Size	φ 3.5	φ 11	φ 18
Welding pressure (kN)		1	8	22
Welding time (cyc.) 50Hz	Sq.T	20	30	40
	W.T	6	65	20-5 (9N)
	Ho.T	6	35	90
Welding current (kA)		7.5	15.8	32.5

2.2 Configuration of Weld Test Specimens

Fig. 7 shows the configuration of the weld test specimens. The test specimens conform to JIS Z 3136. The size of the test specimens conforms to Table 19. In order to assess spot weldability, the single-spot weld joint specimen shown in Fig. 7 was used.

Fig. 7 Configuration of Weld Test Specimens (JIS G 3136)

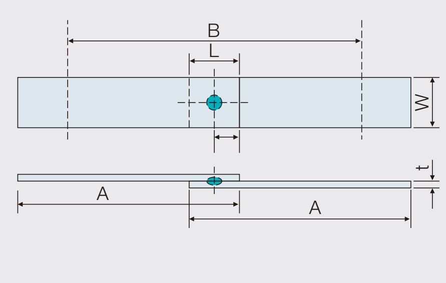


Table 19 Size of Weld Test Specimens (JIS G 3136) (unit: mm)

Nominal thickness (t)	Width (W)	Lap allowance (L)	Test specimen length (A)	Distance between clamps (B)
0.3≦t<0.8	20	20	75	70
0.8≦t<1.3	30	30	100	90
1.3≦t<2.5	40	40	125	100
2.5≦t≦5.0	50	50	150	110

3. Assessment Methods

Tension shear tests were conducted employing weld test specimens. The test specimens for sectional macroscopic observation were extracted from weld test specimens, for which welds were assessed.

3.1 Tension Shear Tests (JIS Z 3136)

In order to examine the tensile shear strength of welds, tension shear tests were conducted employing weld test specimens. The test method conforms to JIS Z 3136. The target tensile shear strength (kN) of the welds was determined employing the values in Table 22 of JIS Z 3140 (Average Values of Class A: Reference Materials 2) and the complementary values for base metals in Table 22 for plate thicknesses of t≦4.5 mm. For thicknesses of t≧6 mm, the target tensile shear strength was calculated by the following expression employing the target nugget diameter (dn [mm]) and the specified tensile strength (N/mm²) of the base metals.

$$TSS = \frac{\pi\, dn^2}{4}\, TS$$

TSS: Tensile shear strength (kN): dn: Nugget diameter (mm); TS: Specified tensile strength (N/mm²)
Based on the above, target tensile shear strength is shown in Table 20.

Table 20 Target Tensile Shear Strength

Thickness (mm)	0.4	3.2	9.0
Target tensile strength (kN)	1.3	30	100

3.2 Sectional Macroscopic Observations (JIS Z 3139)

Macroscopic tests were carried out in order to confirm that the nugget diameter of welds satisfies the target nugget diameter and to clarify the penetration condition.

The tests were conducted in conformity with JIS Z 3139. The tests were conducted on cross sections perpendicular to the sheet surface, sections near the center of the weld point were cut by an appropriate method, and nugget diameter was measured after grinding and corrosion.

4. Assessment Results

Table 21 Tensile Shear Strength

Thickness (mm)	0.4	3.2	9.0
TSS (kN)	2.61	52.1	117.2

4.1 Tensile Shear Test Results

Steel sheets with respective thicknesses were spot-welded respectively under the conditions shown in Table 18. Tensile shear tests were then conducted, the results of which are shown in Table 21. The strength is the average strength, N=11.

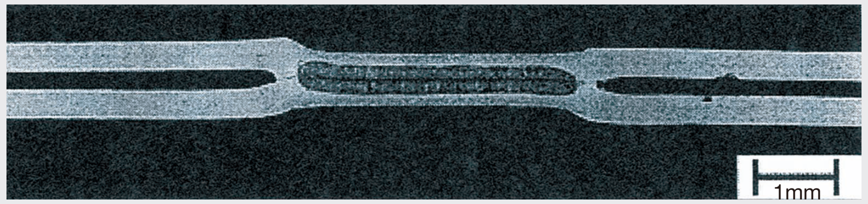
It was confirmed by conducting spot-welding under the conditions in Table 18 that the tensile shear strength of spot welds satisfies the target tensile shear strength shown in Table 20.

4.2 Sectional Macroscopic Observations

Fig. 7 shows a sectional macroscopic photo of a typical example (N=1).

The nugget diameter (dn) thus observed was 3.7 mm, which satisfied the target nugget diameter (3.2 mm, Table 23). Meanwhile, sectional photos of other plate thicknesses are shown in Reference Materials 3.

Photo 7 Section of Spot Welds of Coated Sheets (t=0.4 mm, K27)



4.3 References

Effect of coating layers on welds

When spot welding coated sheets, the steel sheet enters a molten state at the weld, but the coating layer with its low melting point is pushed away from the area of the welds before the steel melts. Accordingly, the coating layer is basically excluded from the weld and, thereby, exerts no effect on weldability. Although there are cases in which blow holes remain in the weld metal, it was confirmed that these blow holes do not cause deterioration in weld joint strength if the welding was performed under appropriate welding conditions.

Reference Materials 2 Target Tensile Shear Strength and Target Nugget Diameters in Spot Welding

JIS Z 3140: Spot Welding Inspection Method

Table 22 Tensile Shear Load (Steel) (unit: kN)

Thickness (mm)	A, AF classes		B, BF classes	
	Minimum	Average	Minimum	Average
0.4	1.03	1.23	0.93	1.13
0.5	1.47	1.72	1.32	1.57
0.6	1.91	2.26	1.77	2.06
0.7	2.45	2.89	2.21	2.60
0.8	2.99	3.53	2.70	3.14
0.9	3.58	4.17	3.19	3.78
1.0	4.17	4.90	3.73	4.41
1.2	5.49	6.42	4.95	5.79
1.4	6.91	8.14	6.23	7.31
1.5	7.65	9.02	6.91	8.09
1.6	8.43	9.91	7.60	8.92
1.8	10.1	11.9	9.1	10.7
2.0	11.8	13.8	10.6	12.5
2.3	14.5	17.1	13.0	15.4
2.5	16.5	19.4	14.8	17.5
2.6	17.5	20.6	15.7	18.5
2.8	19.5	22.9	17.6	20.7
3.0	21.7	25.5	19.5	22.9
3.2	23.8	28.0	21.5	25.2
3.6	28.4	33.4	25.6	30.1
3.8	30.9	36.3	27.8	32.7
4.0	33.3	39.2	30.0	35.3
4.5	39.8	46.8	35.8	42.2
5.0	46.6	54.8	42.0	49.3

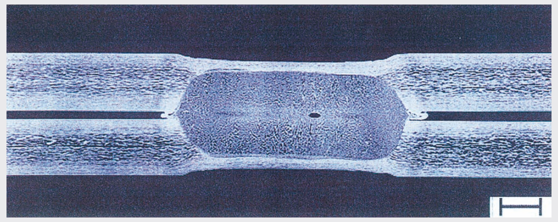
Remarks: When the minimum tensile strength of respective base metals is 370~590 N/mm² in JIS, the target tensile shear strength shall be the above value multiplied by the minimum tensile strength x (8/3000). When the minimum tensile strength surpasses 590 N/mm², the minimum tensile strength shall be set at 290 N/mm², for which the target tensile shear strength shall be the above value multiplied by 1.6.

Table 23 Target Nugget Diameters

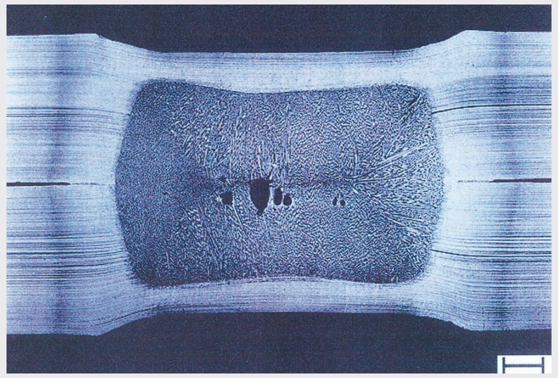
Thickness (mm)	0.4	0.6	1.0	1.6	2.3	3.2	4.5	6.0	7.5	9.0
Target nugget diameter (mm)	3.2	3.9	5.0	6.3	7.6	8.9	10.6	14.7	16.4	18

Reference Materials 3

Photo 8 Sectional Photo and Nugget Diameter after Spot Welding



t=3.2mm dn=12.5mm 2mm



t=9.2mm dn=18.0mm 2mm

Procedures for High-frequency Welding of SUPERDYMA

1. Scope of Applications

These procedures apply to the high-frequency welding of SUPERDYMA with plate thicknesses from 0.8 mm to 9.0 mm and coating masses from K06 to K45 in coating mass symbols.

Regarding coated sheets with coating mass symbols greater than K27, the coating layer is to be removed according to the procedure in section 4, whereupon welding will then be conducted.

2. Welding Methods and Conditions

One of the following two welding methods shall be applied: high frequency induction welding in which steel sheets are welded after being heated and melted by an induction current from work coils, or high-frequency resistance welding in which steel sheets are welded after being supplied with electric current via contact terminals, heated and then melted. Appropriate welding conditions shall be confirmed in advance by conducting the tests in section 3.

3. Tests to Establish Welding Conditions

Whether or not appropriate welding has been performed will be confirmed by conducting flattening tests (JIS G 3444) and macroscopic tests.

3.1 Flattening Tests

3.1.1 Test Specimens

A 50-mm section is extracted from a steel pipe for use as the specimen.

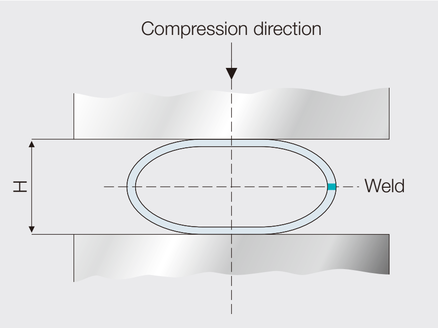
3.1.2 Test Methods

The test specimen is sandwiched between two flat plates at room temperature; the distance between the plates is then compressed to the prescribed value to flatten the specimen. However, the weld is positioned perpendicular to the direction of compression as shown in Fig. 8. The distance between the plates conforms to Table 24.

3.1.3 Assessment

There is no occurrence of scratching or cracking in the weld of the pipe.

Fig. 8 Outline of Flattening Tests



3.2 Macroscopic Tests

3.2.1 Test Specimens

A piece of steel about 20 mm in width from the center of the weld is cut from the steel pipe and used as a specimen.

3.2.2 Test Methods

The test specimen is embedded, ground and etched : and it's sectional microstructure is to be observed with the naked eye or with an optical microscope set at a magnification of about 10x.

3.2.3 Assessment

As shown in Fig. 9, the melted/solidified layer and the metal flow angle are judged.

① Melted/Solidified Layer

The melted/solidified layer nearly perpendicular to the thickness center line is clearly witnessed.

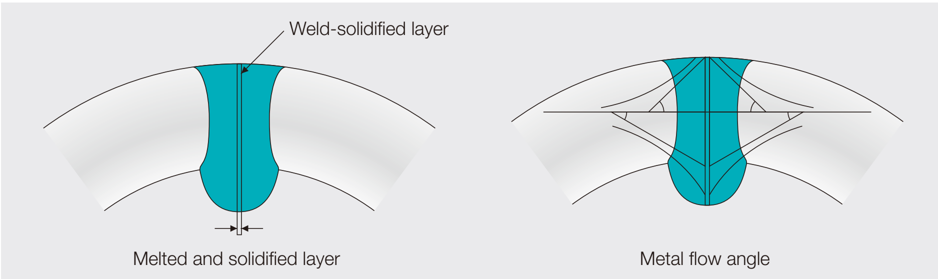
② Metal flow angle

The standard angle is nearly symmetrical and within the range of 30~70º.

Table 24 Distances between Flat Plates in Flattening Tests

Mechanical properties	Distances between flat plates (H)
400N	2/3D
490N	7/8D

Fig. 9 Assessment of Macroscopic Tests



4. Method to Remove Coating Layers

In cases when the coating mass is greater than K27, the coating layer is removed by means of acid-pickling removal or mechanical grinding. Meanwhile, although the coating layer does not need to be entirely removed, it should be reduced so that the width more than the weld bead width become smaller than the thickness equivalent to K27.

Assessment Test Results for High-frequency Welding of SUPERDYMA

In order to assess the high-frequency weldability of SUPERDYMA, weldability testing was conducted on steel sheet with a heavy coating mass (coating mass symbol: K27) and thin plate thickness, which is considered to require the strictest welding conditions.

The weldability was assessed by conducting flattening tests and macroscopic tests to confirm that SUPERDYMA possesses favorable high-frequency weldability.

1. Test Specimens

Table 25 shows the details of the steel materials used for the test.

Table 25 List of Test Specimens

Thickness (mm)	Specified tensile strength (N/mm²)	Coating mass symbol	Chemical composition (%)					Mechanical properties			Coating mass (Both sides, g/m²)
			C	Si	Mn	P	S	Yield point (N/mm²)	Tensile strength (N/mm²)	Elongation (%)	
0.8	400	K27	0.17	0.013	0.47	0.014	0.011	340	490	32	322
1.0	400	K27	0.16	0.011	0.48	0.016	0.009	305	448	32	288
1.2	400	K27	0.18	0.014	0.47	0.015	0.013	323	438	33	302

2. Welding Conditions

Welding was conducted employing the high-frequency welding method. Table 26 shows the welding conditions.

Table 26 Welding Conditions

Thickness (mm)	Tensile strength (N/mm²)	Pipe diameter (mm)	Pipe-making speed (m/min.)	Plate voltage (kV)	Plate current (A)
0.8	400	35.0	65	10.0	9.1
1.0	400	35.0	65	10.6	10.0
1.2	400	35.0	65	11.4	10.5

3. Assessment Items

In order to make an assessment, various kinds of tests in addition to flattening tests (JIS G 3444) and macroscopic tests were conducted.

(1) Flattening Tests

Regarding cases in which the weld is positioned perpendicular to the compression direction and cases in which the weld is positioned in line with the compression direction, tests were conducted for both instances using degrees of compression that conform to JIS and degrees of compression stricter than JIS.

(2) Pipe Expansion Tests

Tests were conducted to examine whether or not scratches or other defects occurred when a pipe was expanded by inserting a tool with a conical top end and a cylindrical lower section.

(3) Flaring Tests

In conformity with JIS G 3472 (Electric-resistance Welded Carbon Steel Pipe for Automobile Structures), tests were conducted to examine whether or not scratches or other defects occurred when a pipe end was flared by a 60º-angle conical tool.

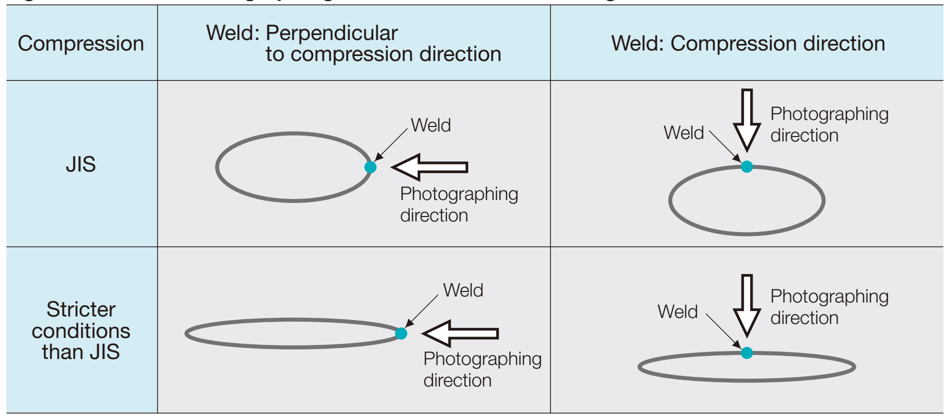
4. Test Results

Photos 9~11 show the test results. Fig. 10 shows an outline of the photographing directions in the flattening tests.

No scratches or cracks occurred in the welds of any test specimens in any of the flattening, pipe expansion or flaring tests.

In macroscopic testing, it was confirmed that an appropriate melted/solidified layer was formed and that the metal flow rising was within a range of 30~70º; appropriate welding was attained. Accordingly, it was found that when welding hot-dip Zn-Al-Mg alloy coated sheets (SUPERDYMA) with thicknesses of 0.8 mm or more and a coating mass symbol of K27 or less, high-frequency welding is possible without removal of the coating layers.

Fig. 10 Outline of Photographing Directions in the Flattening Test



5. References
(Effect of coating layers on welds)

When high frequency welding is performed on coated sheets, the steel sheet enters a molten state at the weld and the coating layer evaporates. Accordingly, the coating layer is essentially excluded from the weld, thereby having almost no effect on weldability. Further, a slight amount of Al oxide is generated; but, because it is pushed away from the weld by the upset, it has no effect on weldability.

Photo 9 High-frequency Weld Test Results for Coated Sheets (thickness: 0.8 mm)

Kind of coating	Thickness	Coating mass symbol	Base metal	Pipe diameter
Zn–Aℓ–Mg coated sheet	0.8mm	K27	400N grades	35.0mm ϕ

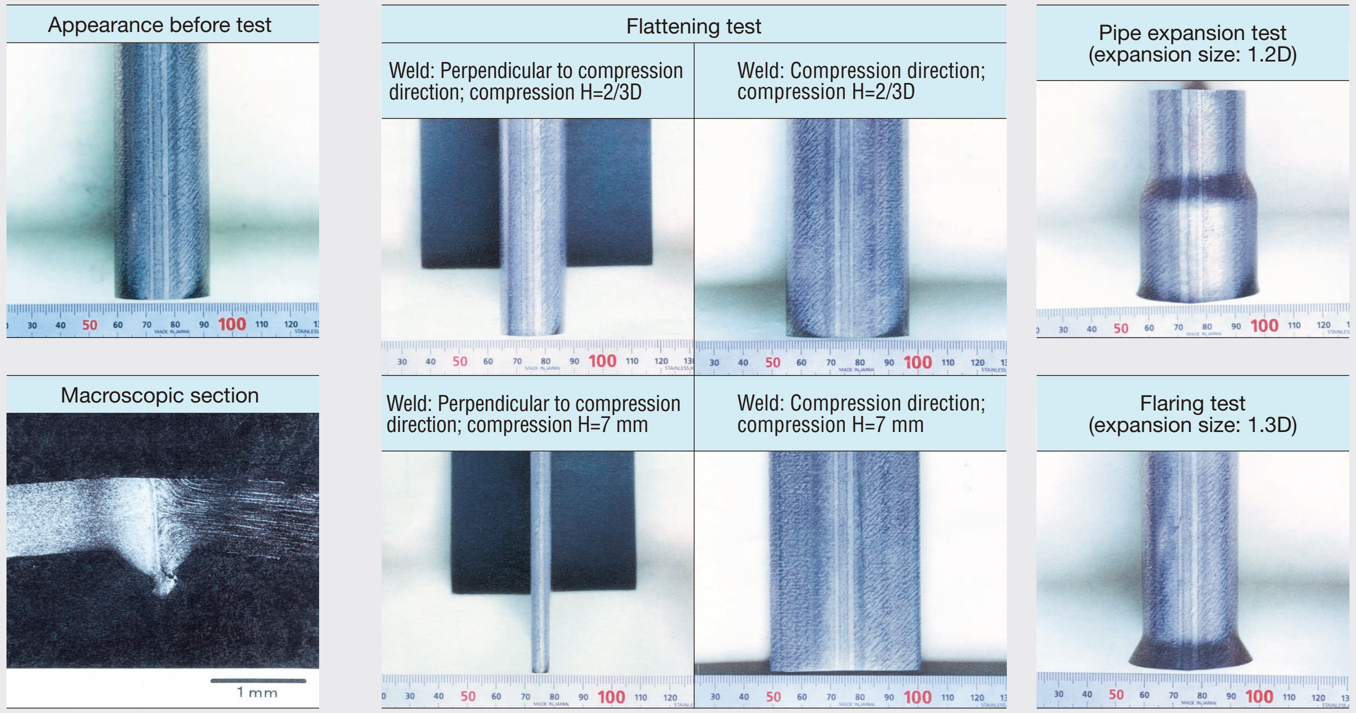


Photo 10 High-frequency Weld Test Results for Coated Sheets (thickness: 1.0 mm)

Kind of coating	Thickness	Coating mass symbol	Base metal	Pipe diameter
Zn–Aℓ–Mg coated sheet	1.0mm	K27	400N grades	35.0mm ϕ

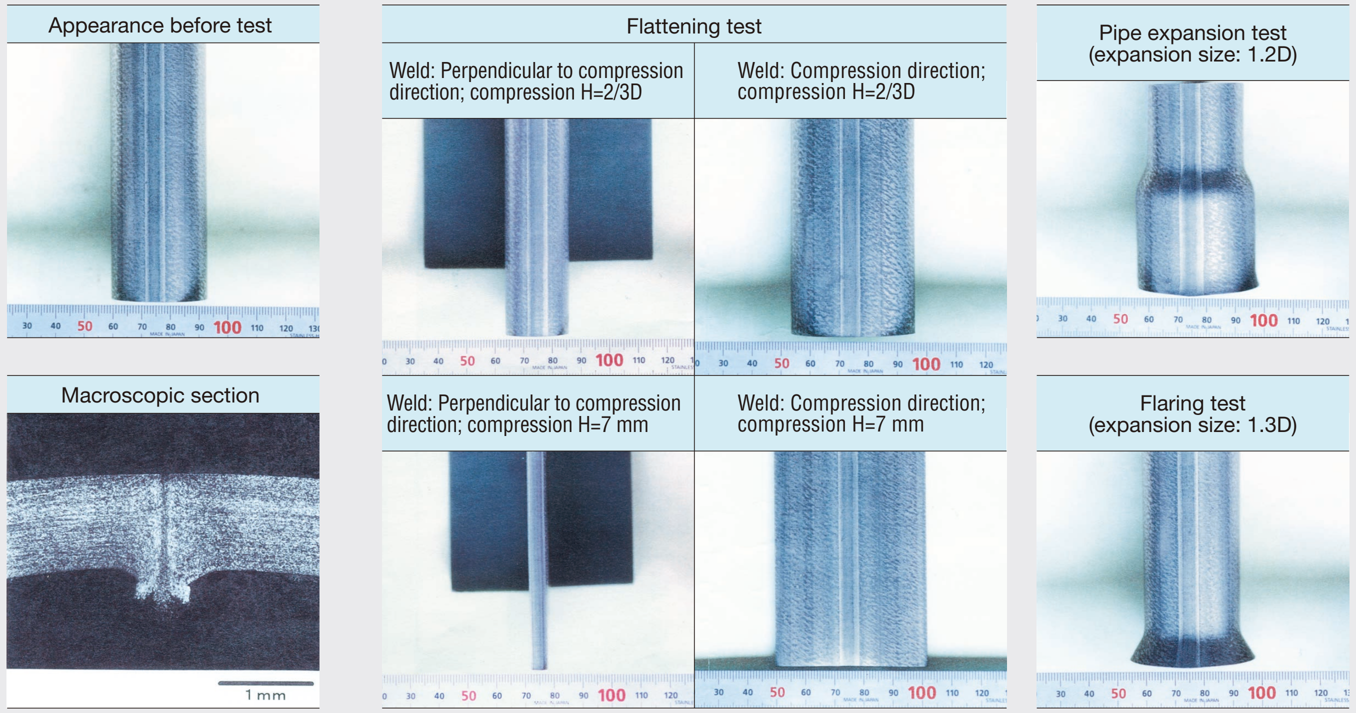


Photo 11 High-frequency Weld Test Results for Coated Sheets (thickness: 1.2 mm)

Kind of coating	Thickness	Coating mass symbol	Base metal	Pipe diameter
Zn–Aℓ–Mg coated sheet	1.2mm	K27	400N grades	35.0mm ϕ