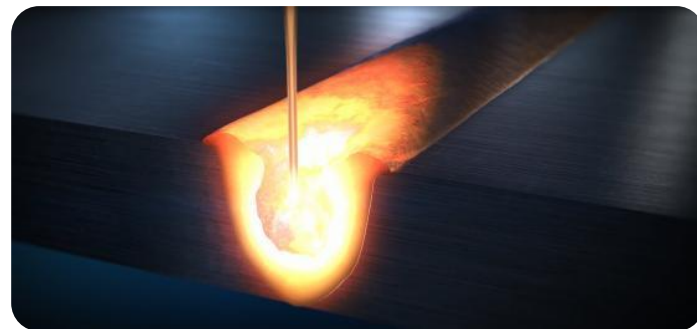
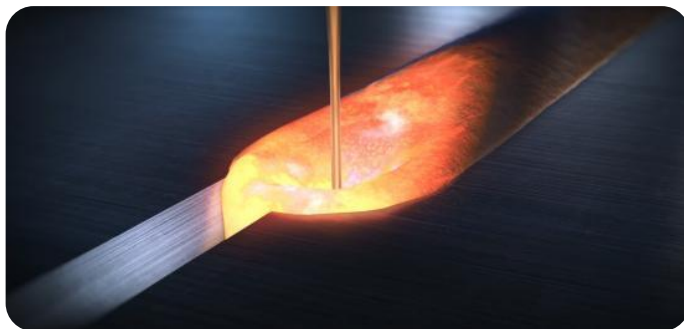


# Highly Efficient Welding System For Heavy Steel Plate: **D-Arc Welding**



**DAIHEN** Corporation



# Contents

- **Outline of D-Arc welding**
- **Intro. of the arc control technology**
- **Thick plate welding by D-Arc**
- **Application to typical weld joints**
- **Basic specifications (for ref.)**

# Contents

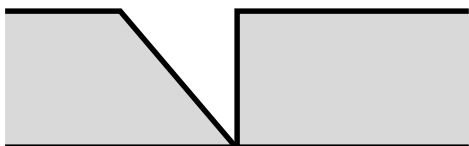
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# Background of development

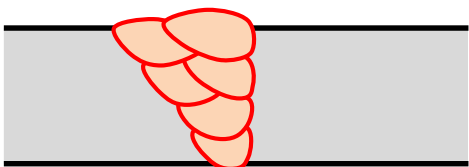
For recent active cost savings in the production of large-scale structures, **higher efficiency in thick plate welding** is strongly requested.

## Problems in conv. welding

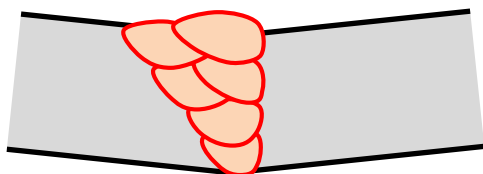
Large groove area



Multi-pass welding



Large welding distortion

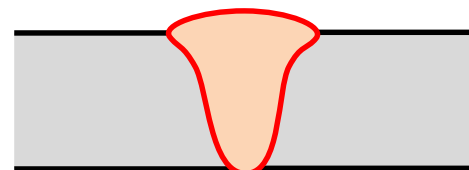


## Aim of D-Arc welding

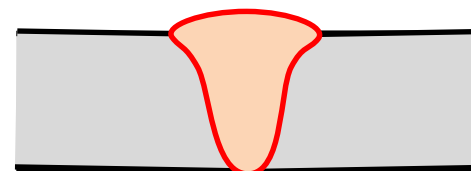
Non-groove welding



Thick-plate single-pass welding



Reduction of welding distortion



# D-Arc welding can be defined as

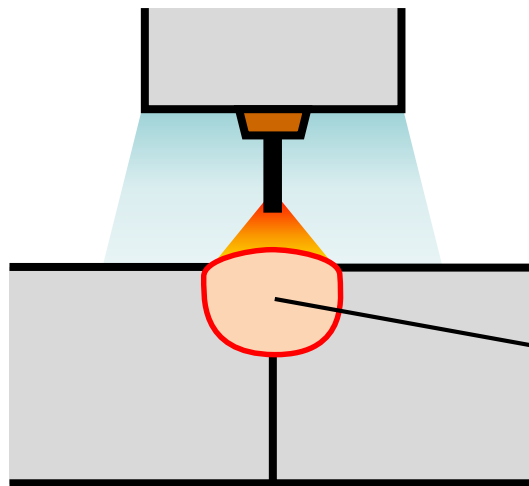
the **highly-efficient thick-plate welding**  
by **high-current buried arc**.

CG image



# Buried arc welding vs. general arc welding

General arc welding



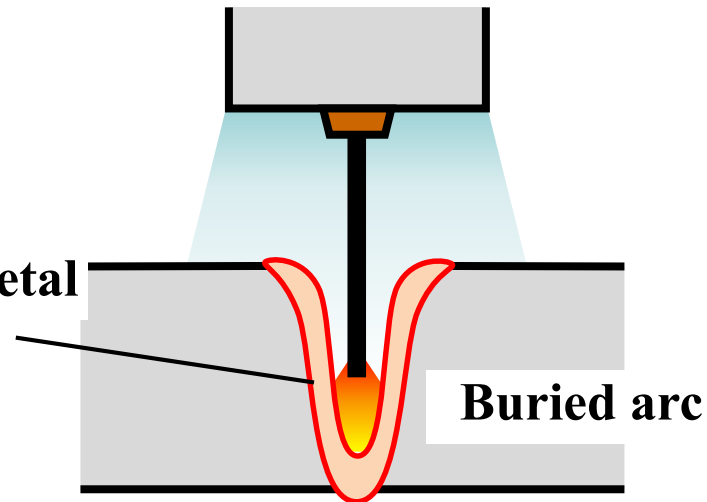
Molten metal

Arc generates  
above the molten metal.

Only molten metal's upper part is heated,  
resulting in shallow penetration.

Stable welding can basically  
be executed.

Buried arc welding



Buried arc

Arc generates with the wire  
buried deeply in the base metal.

Deeper part of base metal is heated,  
resulting in deeper penetration.

Molten-metal wall must be held  
for stabilized welding.

# Principle of D-Arc welding

6

**System and waveform control for stabilization of high-current buried-arc welding**

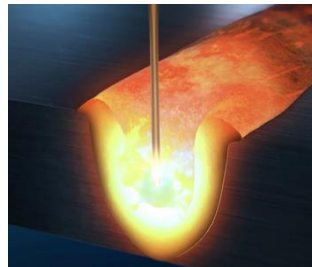
## High-power welding system

High-output power source  
welding current: **max 650A**

High-speed wire feed system,  
feed speed: **max 30m/min**

Water-cooled torch for  
high current: **max 650A**

## Buried arc



## Control tech.

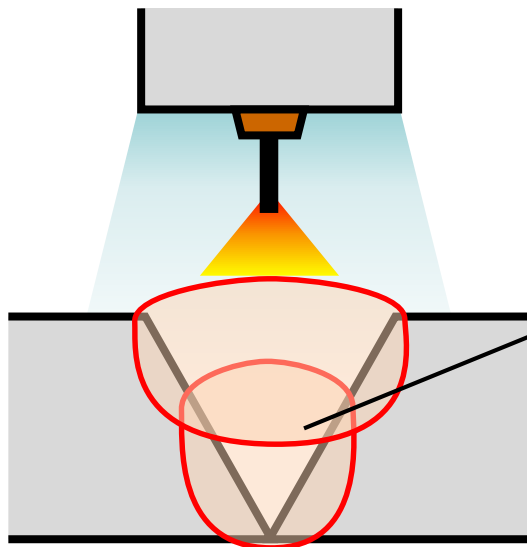
Welbee's precise  
waveform control  
**stabilizes a buried arc.**



**Both system and control have achieved a stable high-current buried arc.**

# Comparison with conv. high-current welding

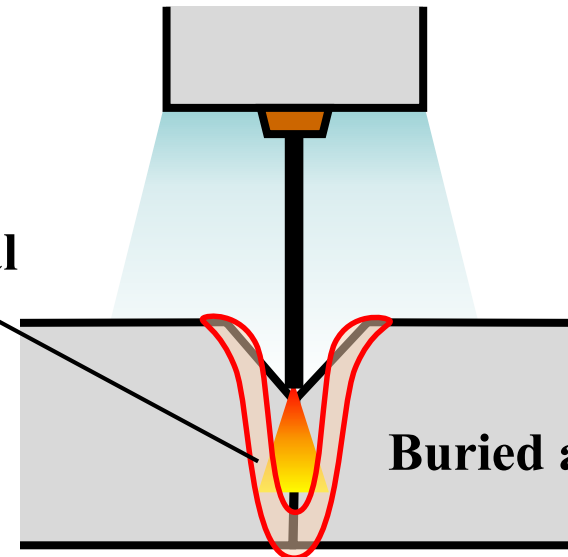
## Conv. high-current welding



Molten metal

- Higher deposition rate makes the process of "filling" the groove more efficient.
- High deposition rate fills a wide groove.
- The basic concept is to "fill the groove, though the welding efficiency can be improved with a narrow groove.

## D-Arc welding



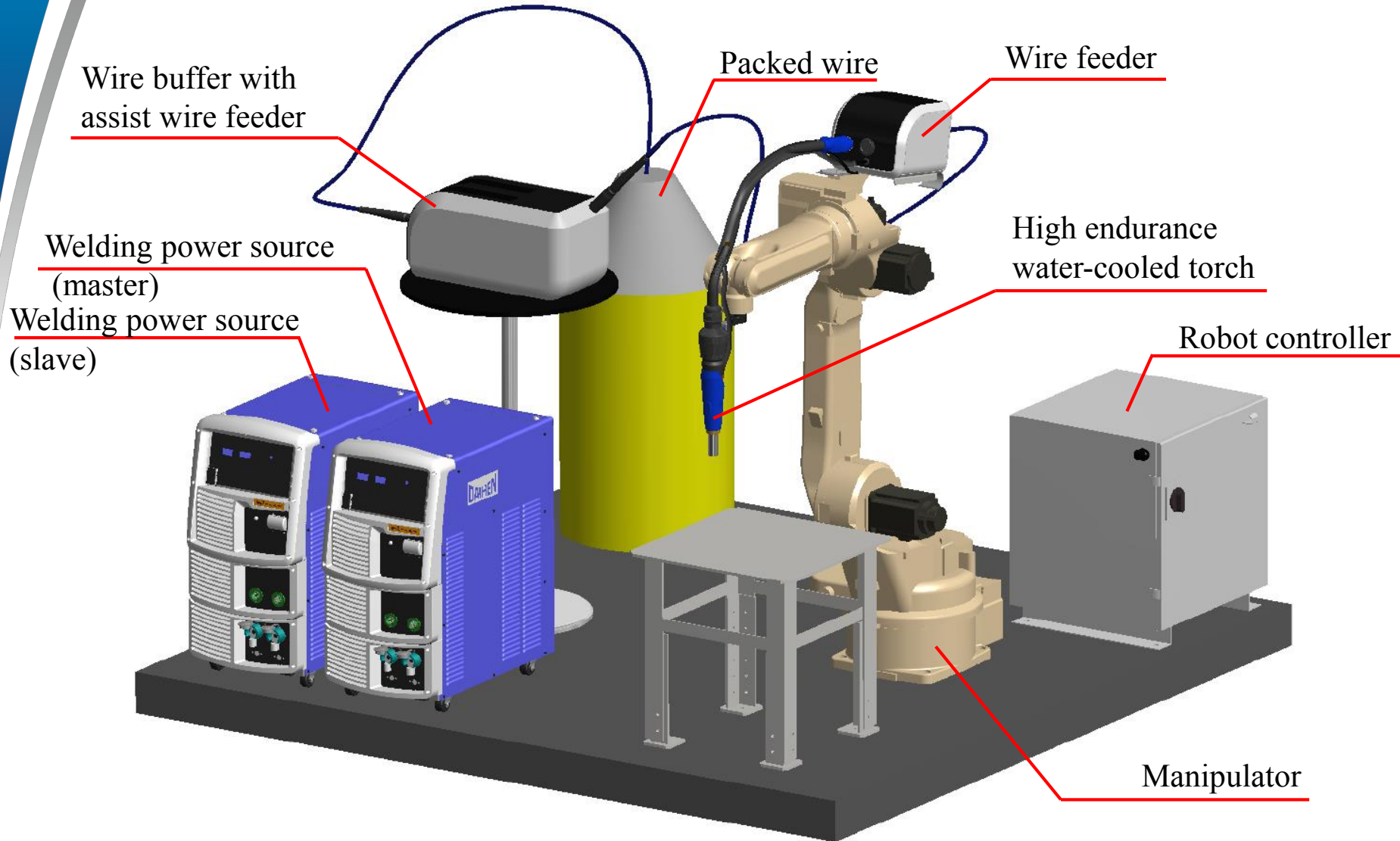
Buried arc

- Deeper penetration minimizes the process of "filling" the groove.
- Deep penetration enables non-groove or narrow-groove welding.
- The amount of deposited metal is less for each penetration depth (or plate thickness).



# Typical robotic system configuration

8



Max. Output: **650A**

Max. Wire-feed speed: **30m/min**

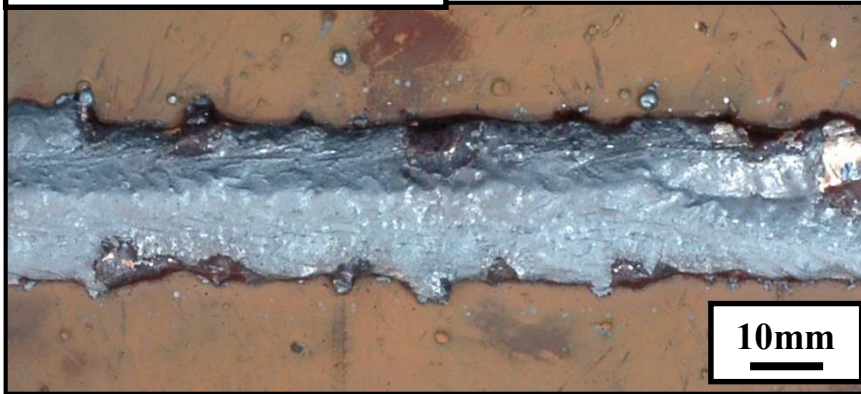
# Contents

- Outline of D-Arc welding
- **Intro. of the arc control technology**
- Thick plate welding by D-Arc
- Application to typical weld joints
- Basic specifications (for ref.)

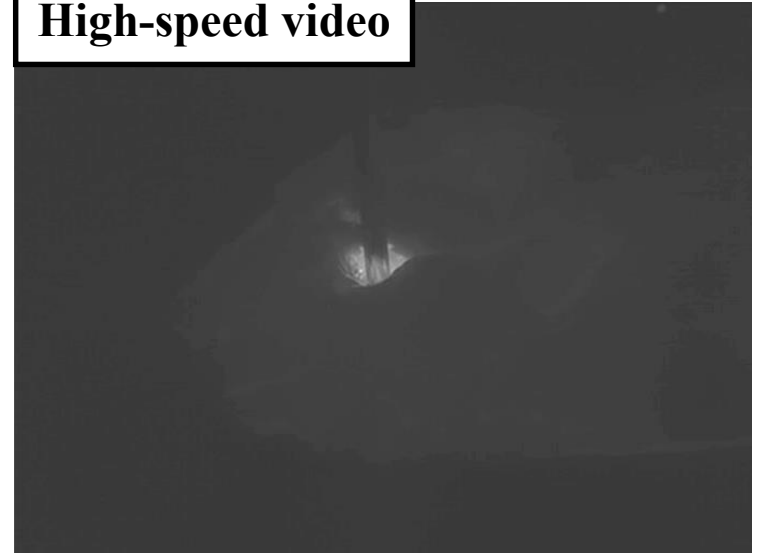
# Observation of general buried arc

Wire feed speed: 40m/min; welding current: 570A; arc voltage: 48V

**Bead appearance**



**High-speed video**



**X-ray transmission observation**



**Buried arc becomes unstable.**



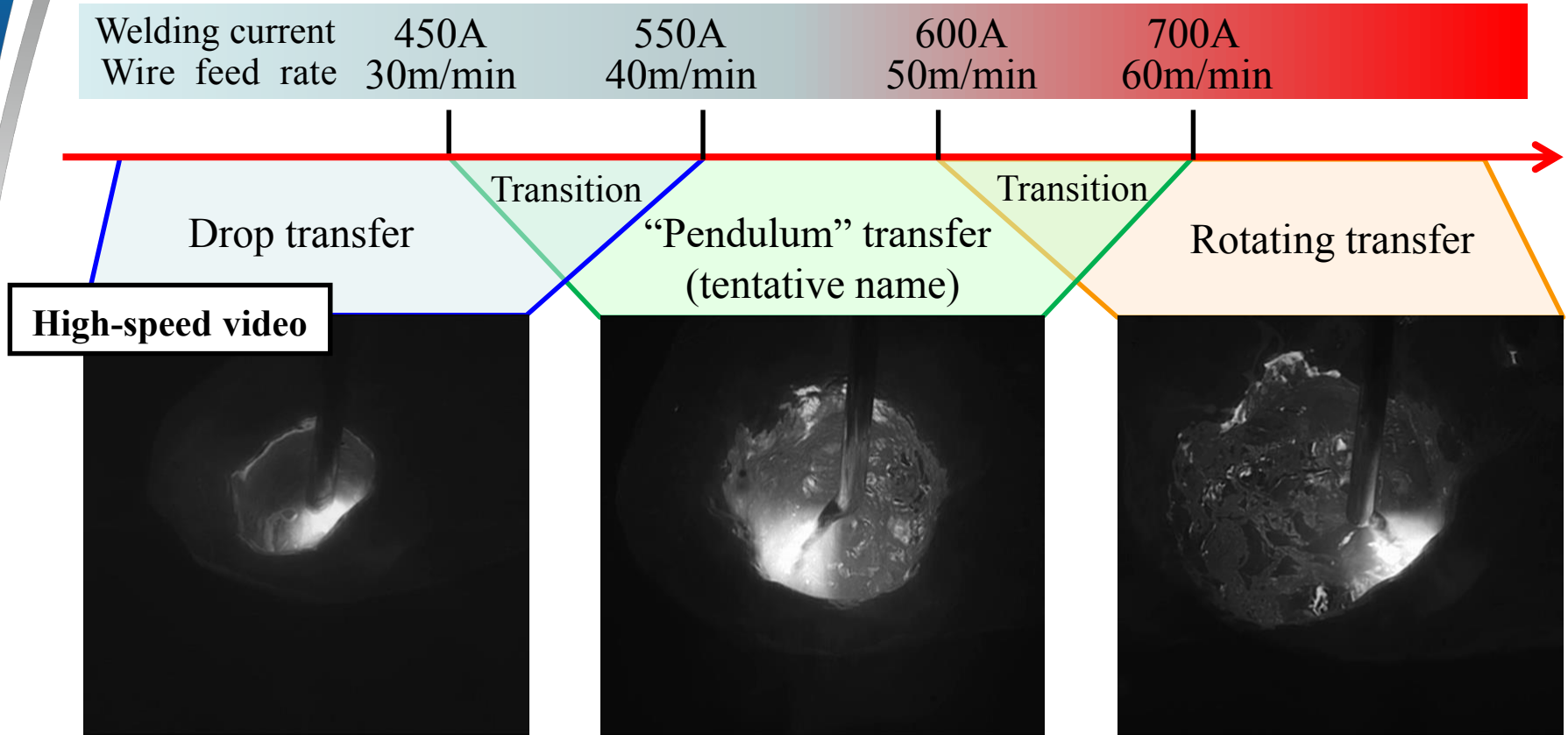
**Weld metal becomes staggered.**



**Bead shape becomes irregular.  
Much spatter generates.**

**How to stabilize the buried arc is an issue !**

# Metal transfer variations in the high-current range

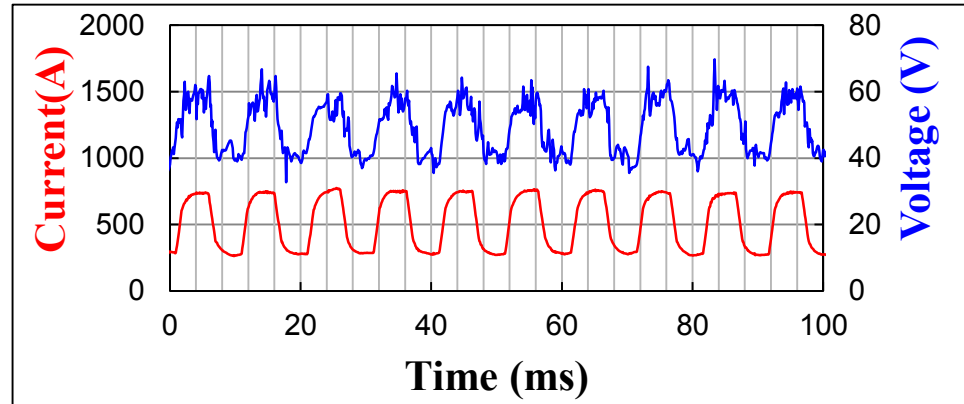
 $\Phi 1.2$ 

Complex metal transfer must be controlled in the high-current range.

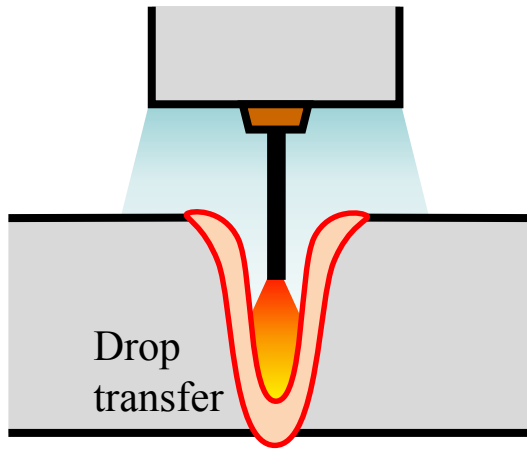
# Stabilization of buried arc in D-Arc

## Low frequency modulated voltage control

The low-voltage and high-voltage sections are periodically repeated in this waveform control.

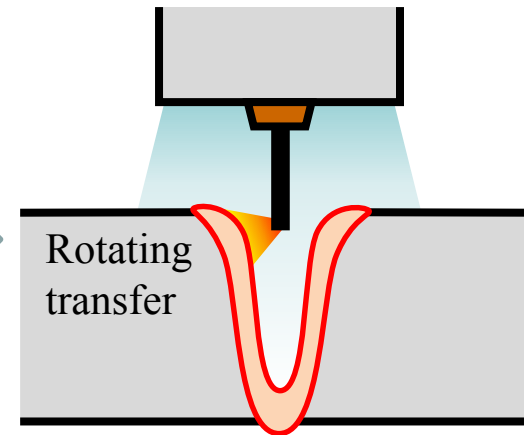


### Low-volt section



The bottom surface is given the heat input to maintain deep penetration.

### High-volt section



The sidewall of molten metal is supported to maintain the space for buried arc.

Repeating

**By controlling the metal transfer's change,  
the stabilization of buried arc has been achieved!**

# Comparison of stability of buried arcs

High-speed video

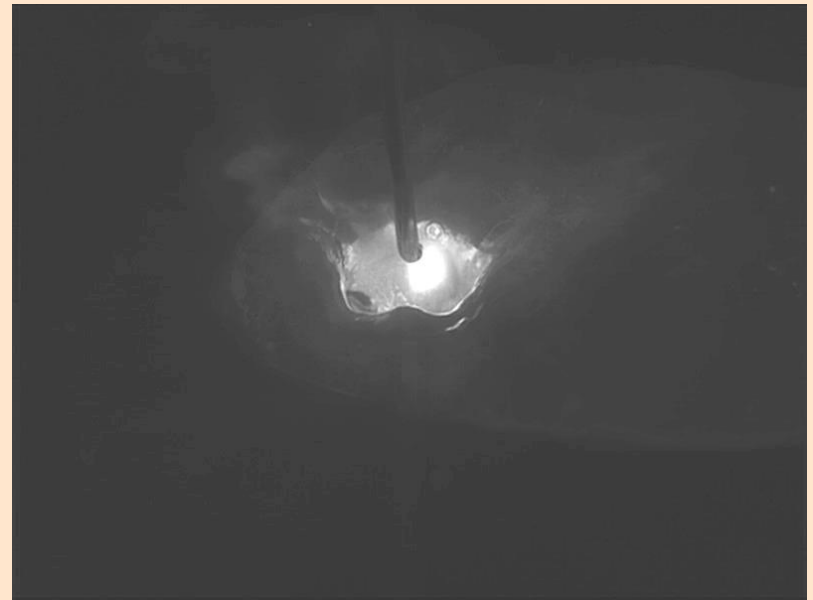
Wire feed rate: 40m/min; Current: 570A; Voltage: 48V; Wire size:  $\phi 1.2$

Without control



The buried space is flickering or unstable.

With control (**D-Arc**)



**The buried space is stable.**

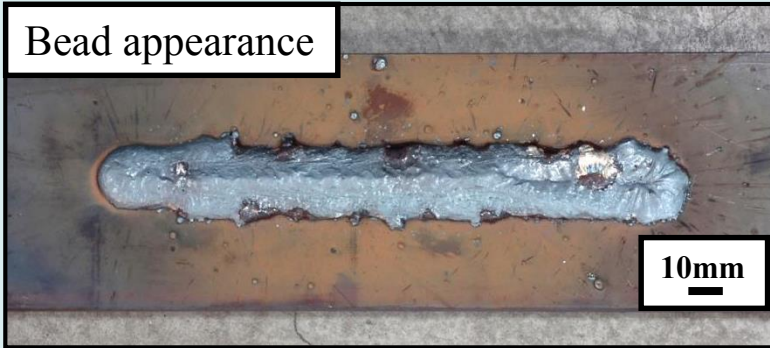


# Comparison of weld beads

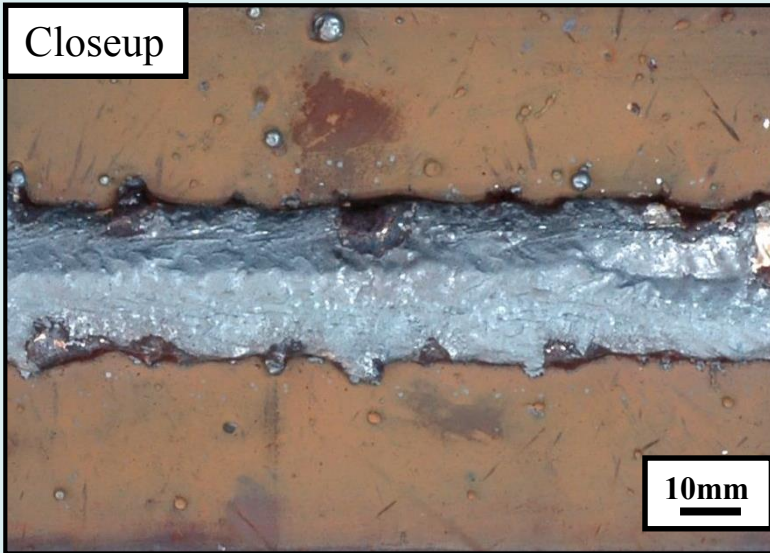
Wire feed rate: 40m/min; Current: 570A; Voltage: 48V; Wire size:  $\phi 1.2$

Without control

Bead appearance



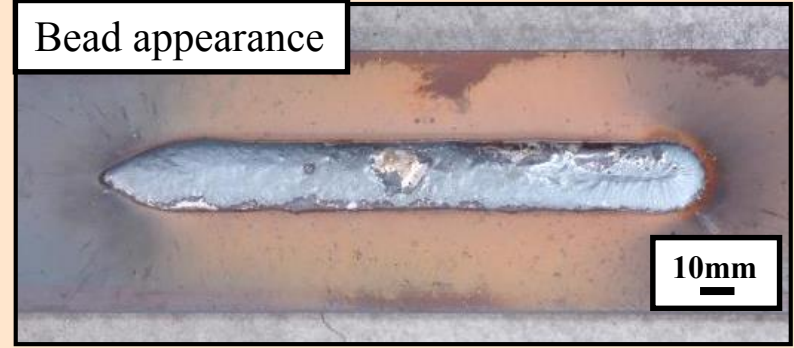
Closeup



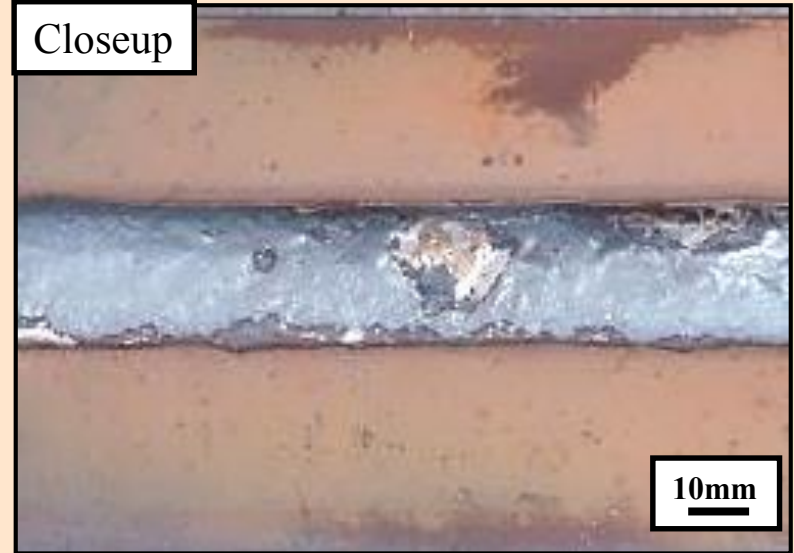
Irregular bead and coarse spatters

With control (D-Arc)

Bead appearance



Closeup



Uniform bead without spattering trace

# Contents

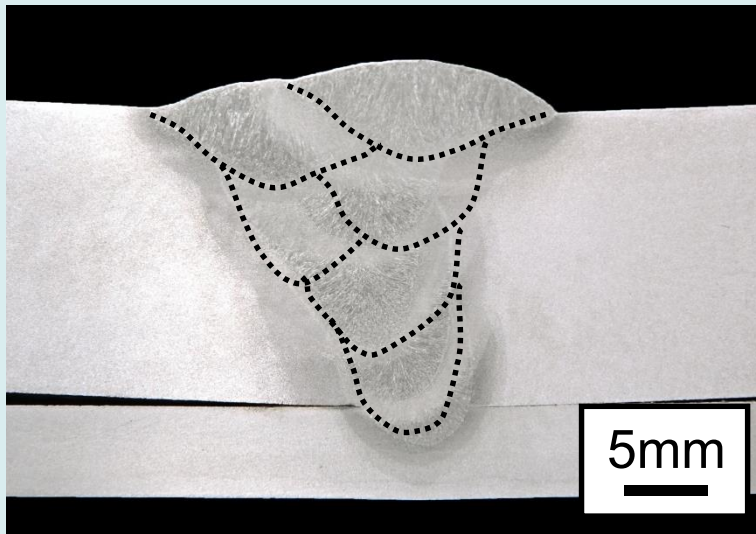
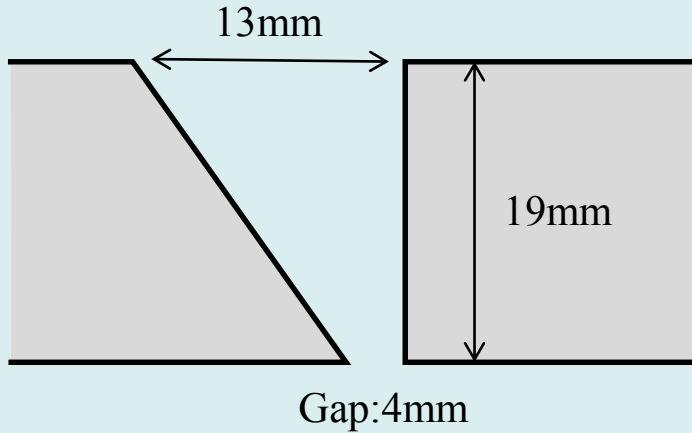
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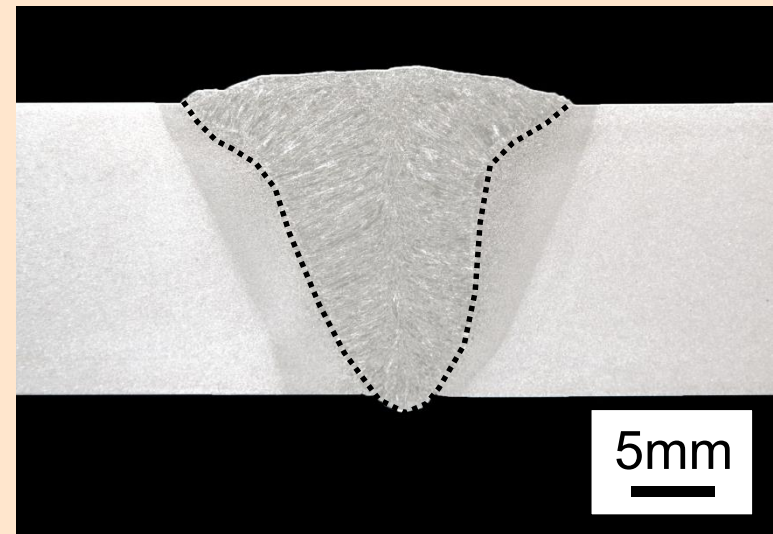
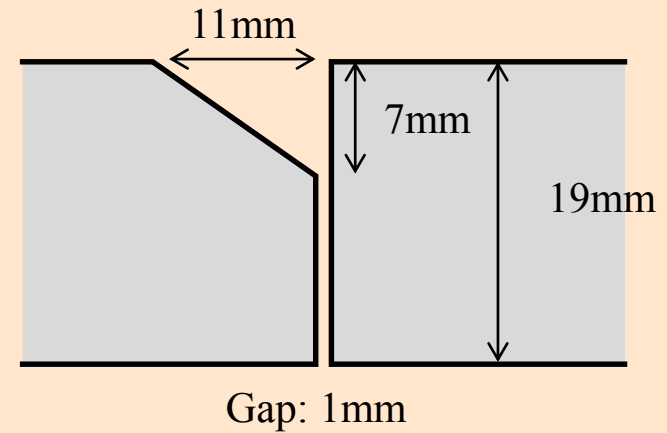
# Welding of 19-mm thick plate

Φ1.4

## Conventional welding procedure



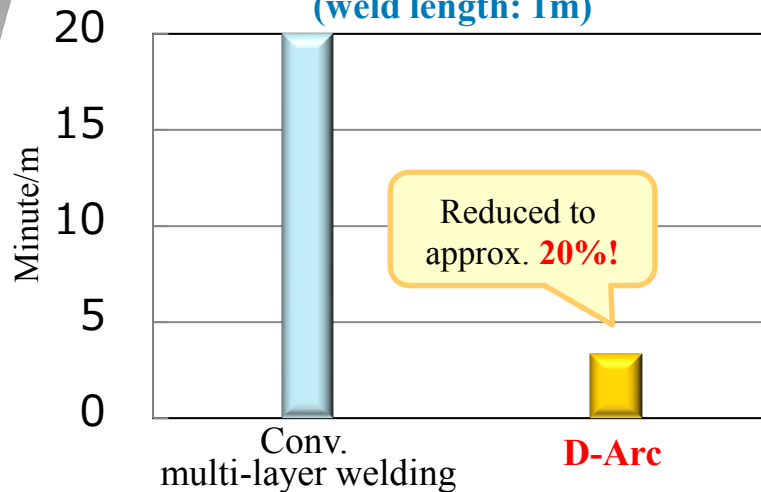
## D-Arc welding procedure



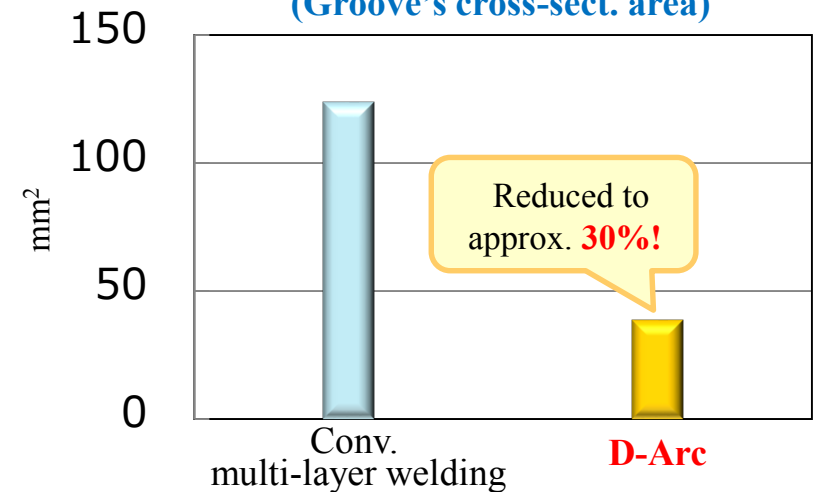
**Highly efficient welding** of thick plates has been achieved by **D-Arc welding**.

# Comparison with conventional welding procedure

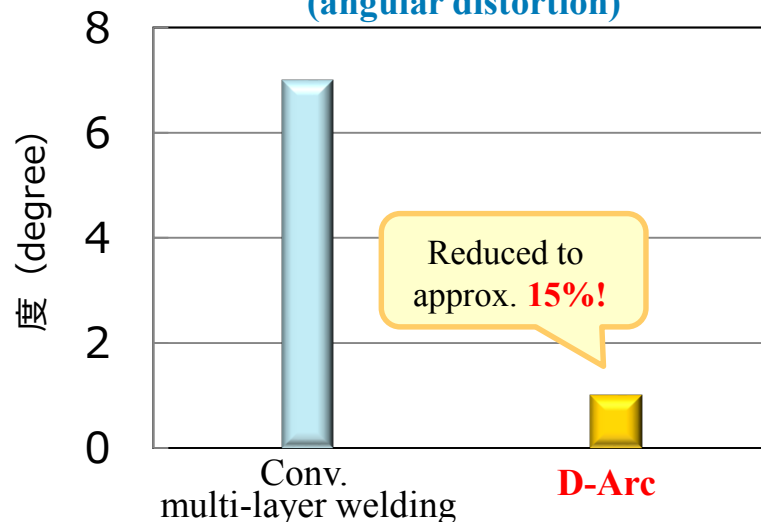
**Welding time**  
(weld length: 1m)



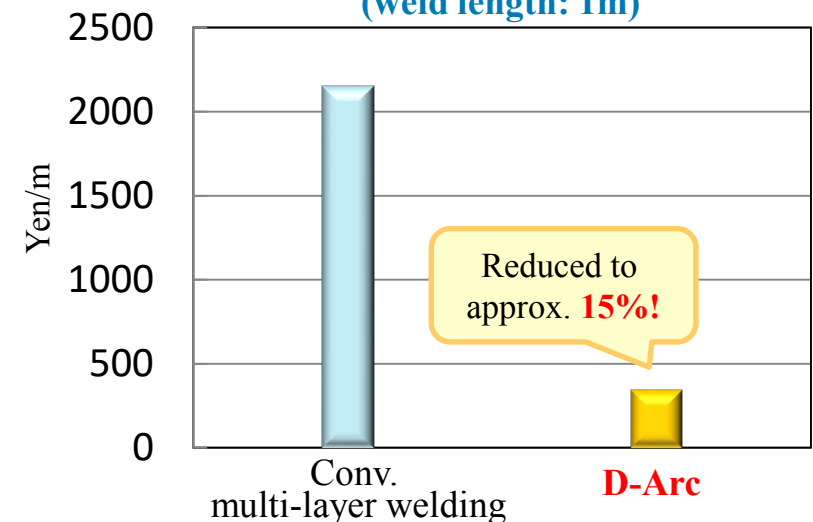
**Groove prep quantity**  
(Groove's cross-sect. area)



**Welding distortion**  
(angular distortion)



**Welding cost**  
(weld length: 1m)

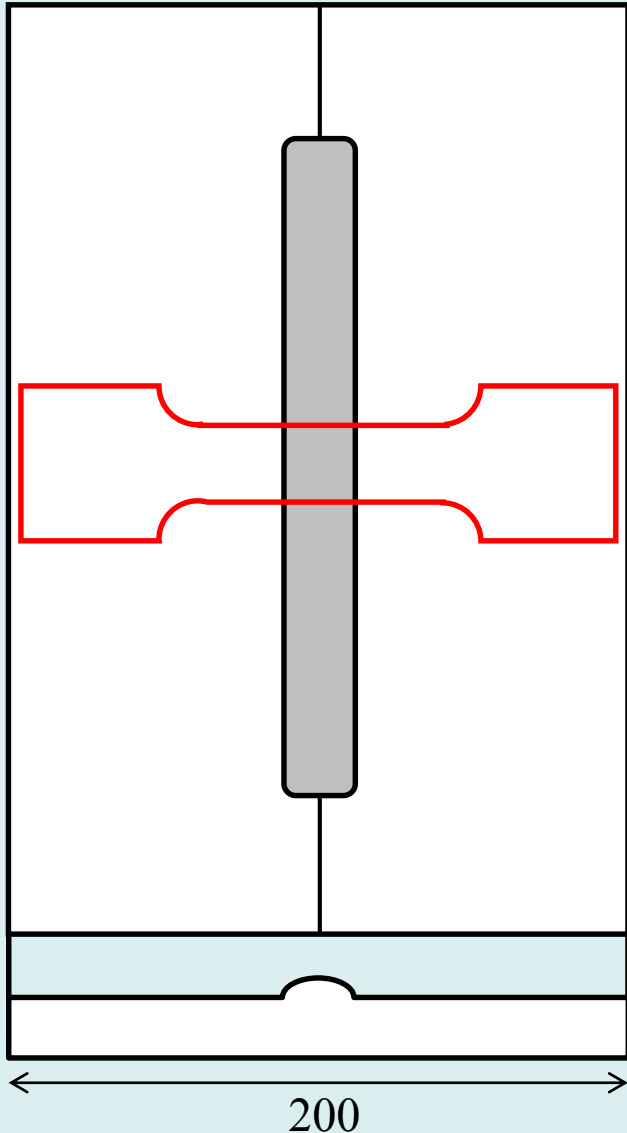




# Mechanical test results of welded joint (SS400) 19

## Tensile test

Welding wire: YGW11,  $\phi 1.4$ ; As per Rules for Construction of Steel Ships(ClassNK)



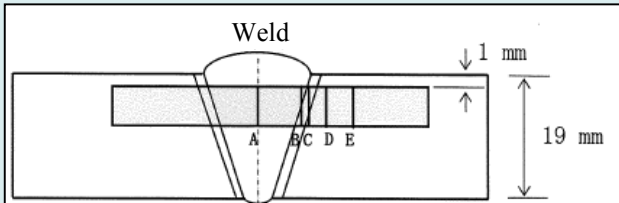
	Tensile strength (N/mm <sup>2</sup> )	Fractured location	Pass or fail
Test piece ①	474	Base metal	Passed
Test piece ②	464	Base metal	Passed
Criterion	400	Not required	—

- Tensile strength exceeded sufficiently the base metal strength.
- Every test specimens fractured at base metal.

# Mechanical test results of welded joint (SS400) 20

## Impact test

Welding wire: YGW11,  $\phi 1.4$ ; As per Rules for Construction of Steel Ships(ClassNK)

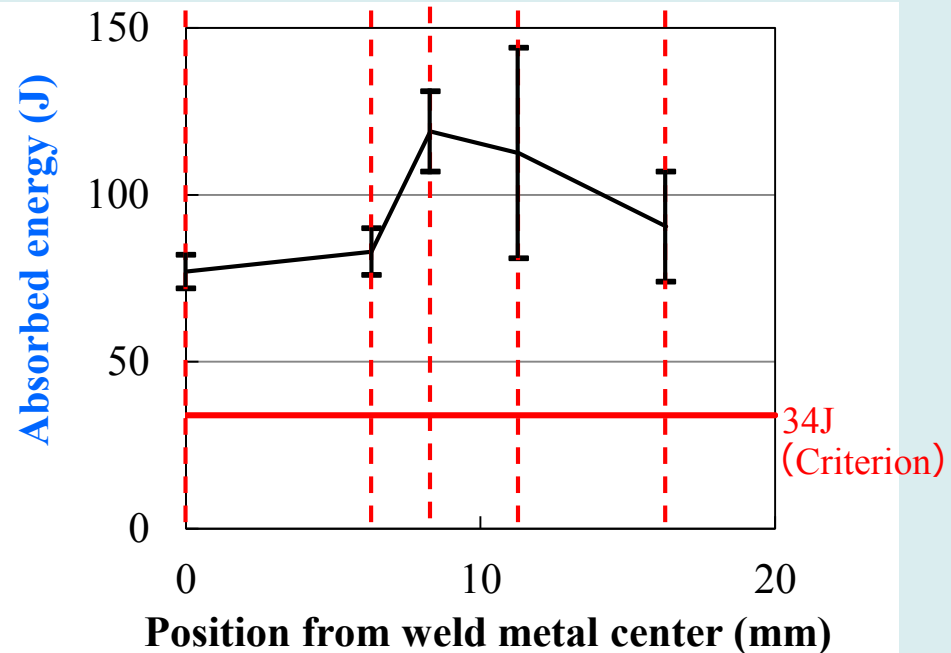
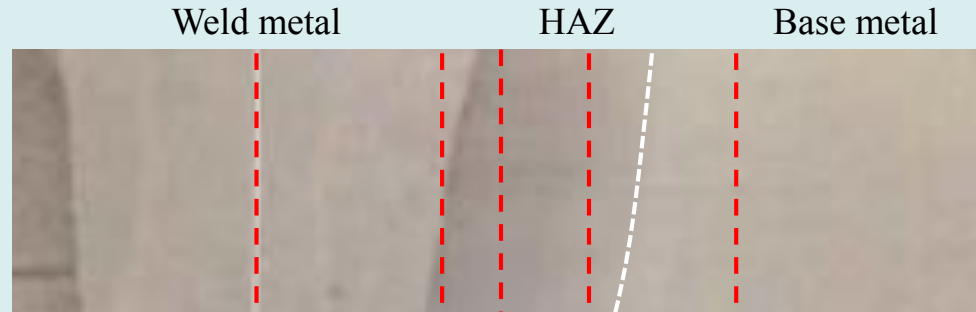


< Location of notch >

- A : Center of weld metal
- B : Fusion line
- C : 2mm to base metal from fusion line
- D : 5mm to base metal from fusion line
- E : 10mm to base metal from fusion line

Toughness was measured at 5 notch locations

Notch location	Absorbed energy(J) ※20°C		Pass or fail
A	72	82	Paseed
B	90	76	Paseed
C	131	107	Paseed
D	144	81	Paseed
E	107	74	Paseed
Criterion	34		—

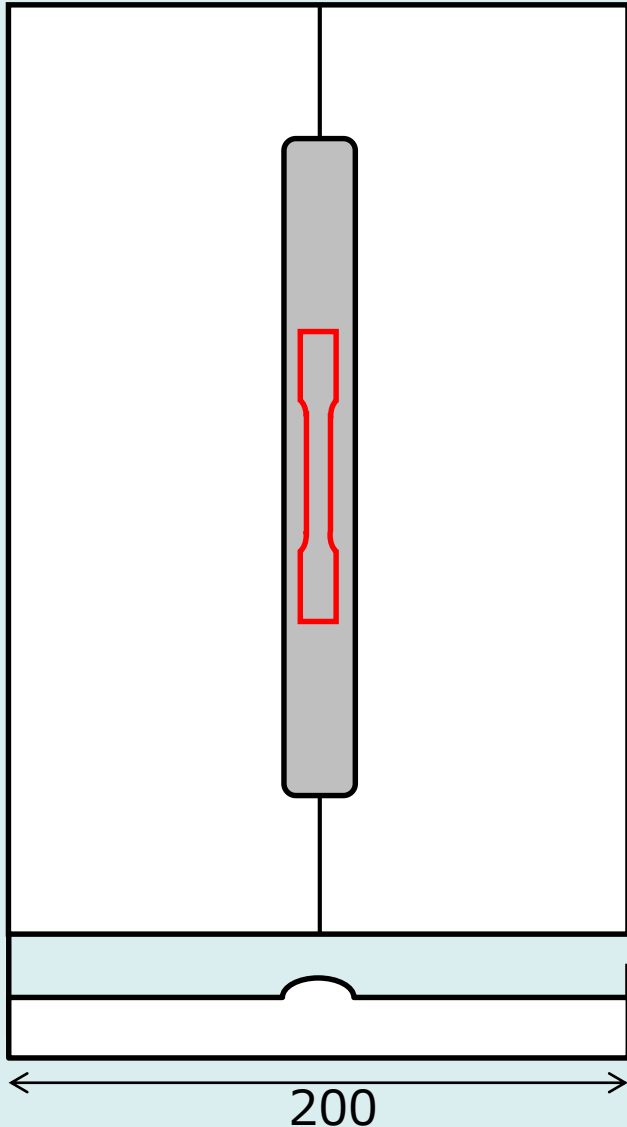


- Toughness was enough to meet the criterion.
- No HAZ embrittlement was observed.

# Mechanical test results of welded joint (SN490C) <sup>21</sup>

Welding wire: YGW18,  $\phi 1$  ; As per JIS Standard

## Tensile test (all-deposited metal)



	Tensile strength (N/mm <sup>2</sup> )	Pass or fail
Test piece ①	689	Passed
Test piece ②	698	Passed
Criterion	536	—

**Tensile strength was confirmed to be sufficient.**

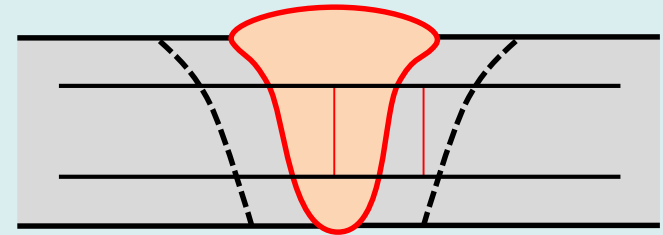
# Mechanical test results of welded joint (SN490C) <sup>22</sup>

Welding wire: YGW18,  $\phi 1$  ; As per JIS Standard

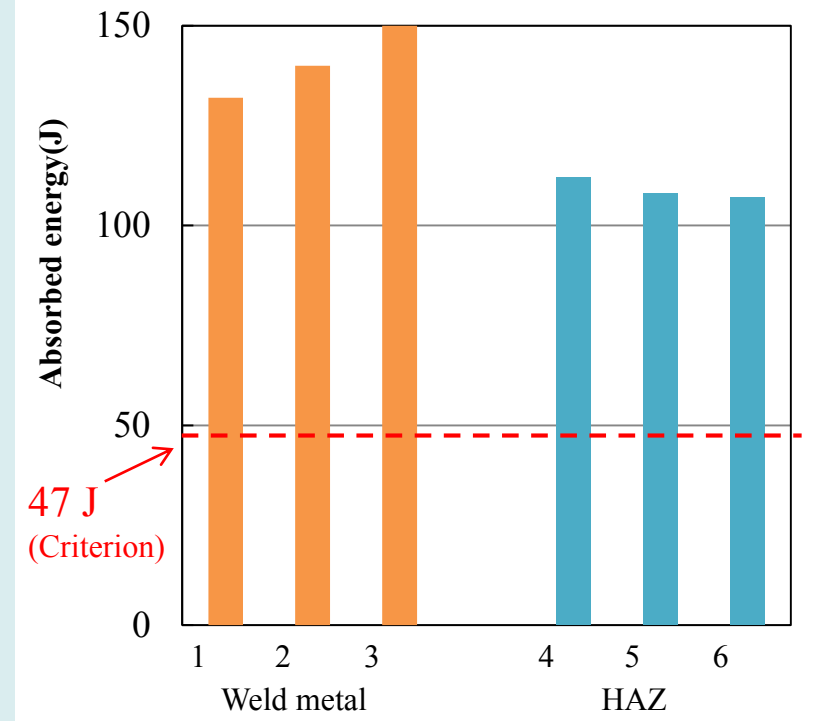
## Impact test

Testing temp. : 0°C

Notch position : At two locations of weld metal center and HAZ center, three specimens were tested, respectively.



	Notch location	Absorbed energy(J)	Brittle fracture area (%)	Pass or fail
Weld metal	1	132	0	Passed
	2	140	0	Passed
	3	150	0	Passed
HAZ	4	112	45	Passed
	5	108	45	Passed
	6	107	45	Passed
	Criterion	47	—	—



**Both weld metal and HAZ exhibited enough toughness to meet the criterion.**

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# Double-sided welding of 25-mm thick plate

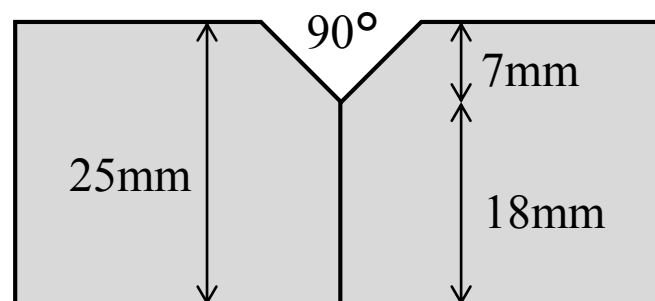
Face side: 580A, 48V, Welding speed of 30cm/min  
Back side: 430A, 40V, Welding speed of 40cm/min  
45°-beveled Y-Groove; Gap: 0mm; Root face: 18mm

**No backing**

Face bead



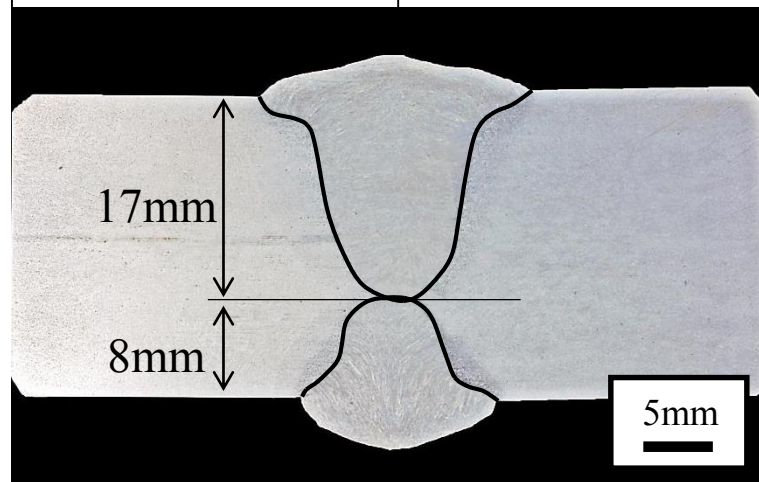
Groove design



Back bead



Cross-sect. macro



**Weld-joint fabrication  
requires no backing.**

# Through-thickness welding of 19-mm thick plate

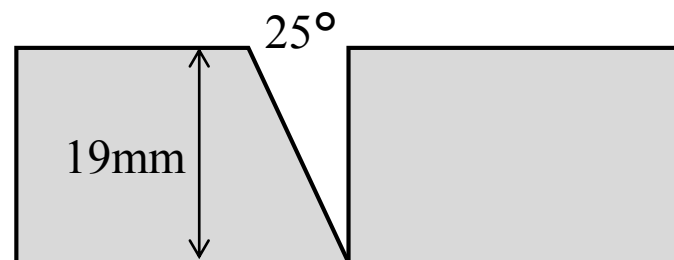
580A, 48V, Welding speed: 24cm/min  
25°-bevel groove, Gap: 0mm

**With ceramic backing**

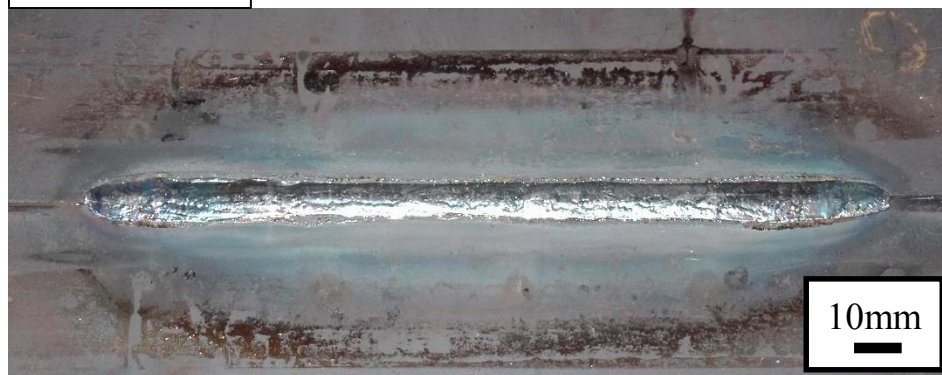
Face bead



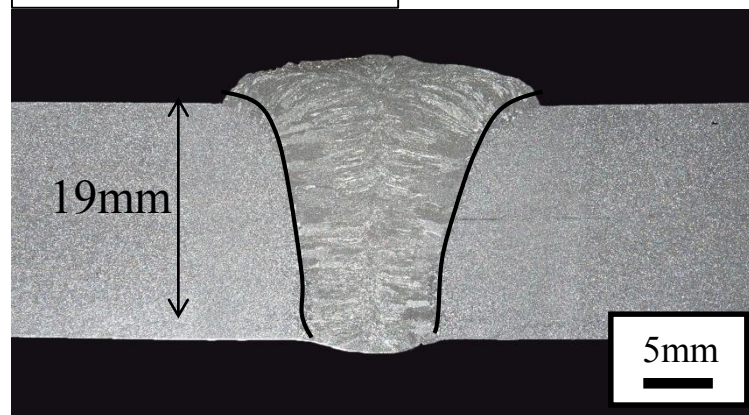
Groove design



Back bead



Cross-sect. macro



**Versatile ceramic backings can be employed.**



# Through-thickness welding of 9-mm thick plate (1)

Face bead

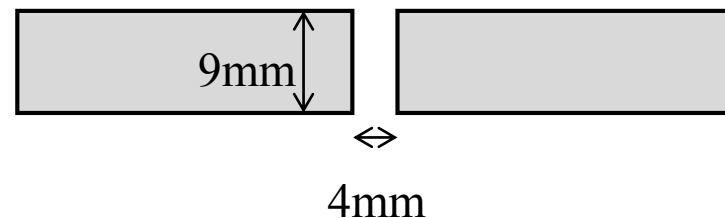


Back bead

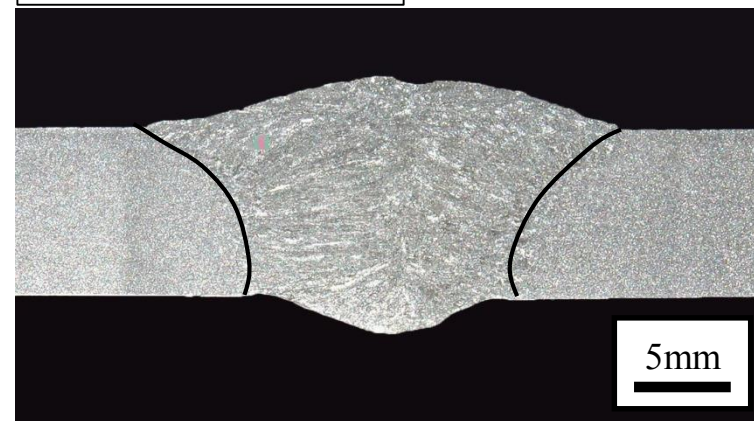


430A, 40V, Welding speed: 30cm/min  
Square groove, **Gap: 4mm**  
With ceramic backing

Groove design



Cross-sect. macro



**Weld-joint fabrication is possible without  
groove preparation (with square groove)**

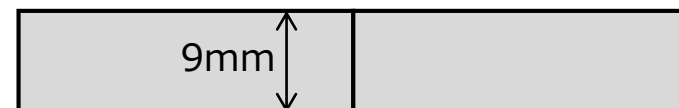
# Through-thickness welding of 9-mm thick plate (2)

430A, 40V, Welding speed: 40cm/min  
Square groove, **Gap: 0 mm**  
With ceramic backing

Face bead



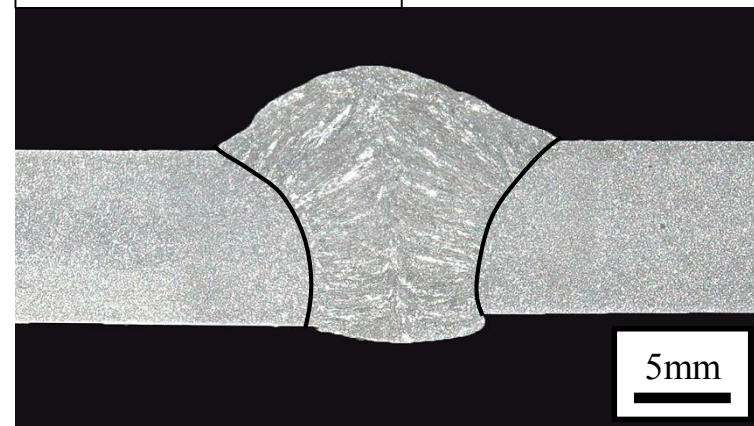
Groove design



Back bead

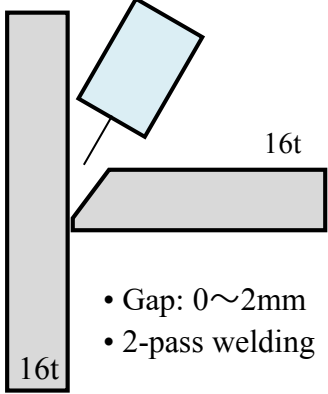
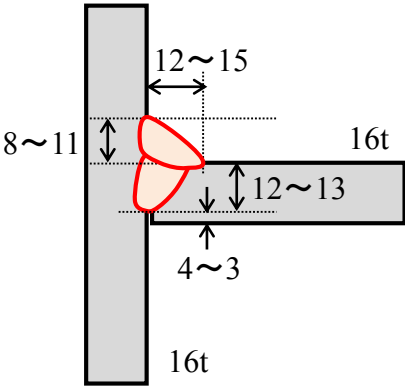
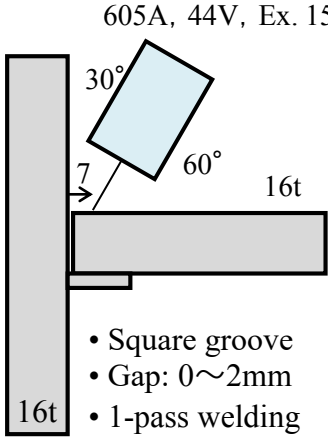
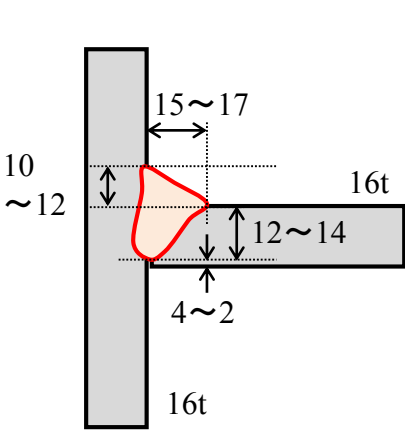


Cross-sect. macro

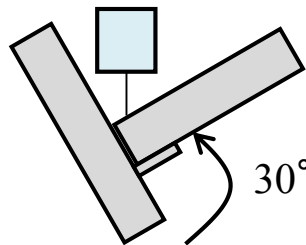


**Weld-joint fabrication is possible  
with 0-mm-gap square groove.**

# T-joint fillet welding in the flat position


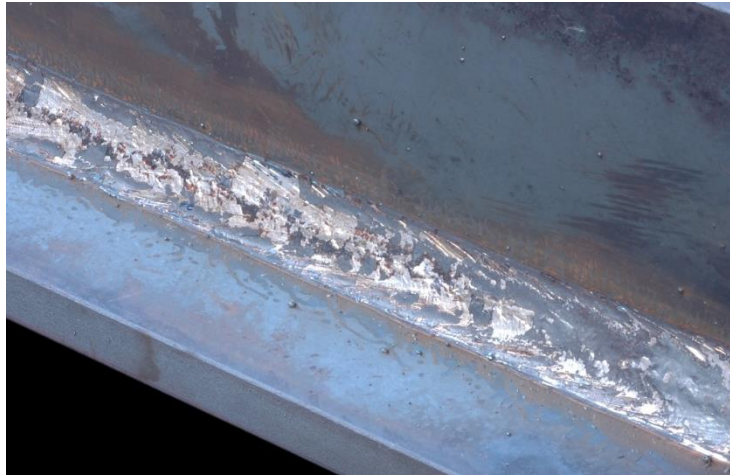
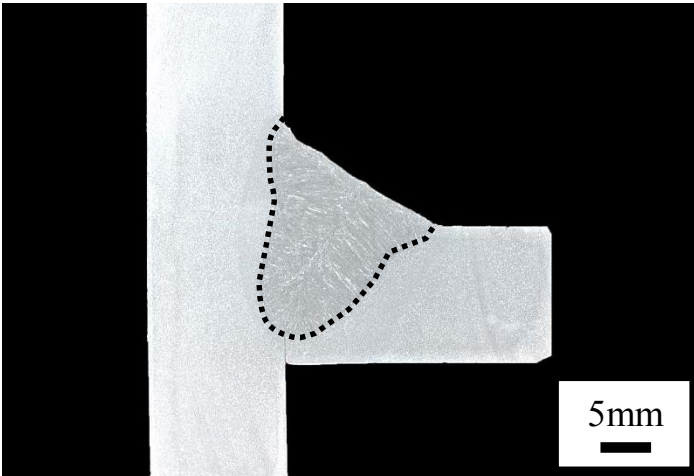
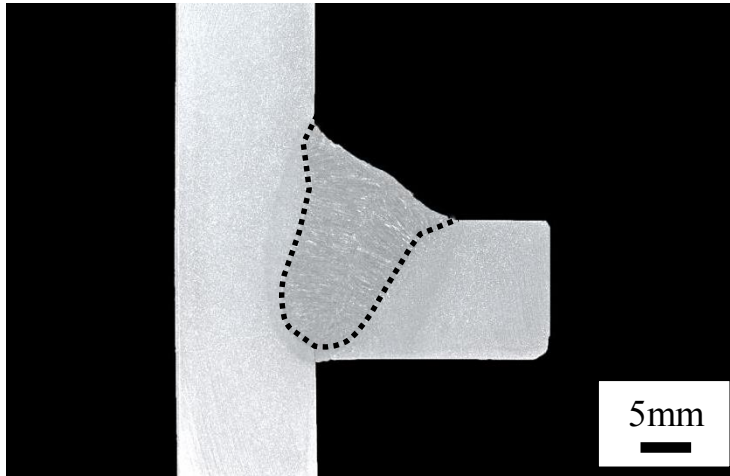
	Before welding	After welding	
Conv. procedure	 <ul style="list-style-type: none"> <li>Gap: 0~2mm</li> <li>2-pass welding</li> </ul>		<p><b>Groove prep is needed.</b></p> <p><b>+</b></p> <p><b>2-pass welding is needed</b></p>
<b>D-Arc</b>	<p>605A, 44V, Ex. 15mm</p>  <ul style="list-style-type: none"> <li>Square groove</li> <li>Gap: 0~2mm</li> <li>1-pass welding</li> </ul>		<p><b>No groove prep is needed.</b></p> <p><b>+</b></p> <p><b>1-pass welding is adequate.</b></p> <p><b>Highly-efficient fillet welding</b></p>

※ The work is rotated by 30 degrees to execute welding with a torch kept vertical..





# T-joint fillet welding in the flat position

	Gap: 0 mm	Gap: 2 mm
Bead appearance		
Cross-sect. macro		

**Extremely-deep-penetration fillet welding can be achieved.**

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# Basic specifications for D-Arc(for ref.)

Process		Note
Welding process	D-Arc welding process	General welding modes are to be dealt with as needed.
Shielding gas	100%CO <sub>2</sub>	30L/min
Grade of wire	YGW11, (12), 18	YGW11 and 18 are recommended.
Wire dia.	1.4 mm	1.2 and 1.6mm are to be dealt with as needed.
Grade of base metal	400MPa class steel 490MPa class steel	Excl. SUS, High alloy steel, special steel.
Welding position	Flat position	
Type of joint	Butt, Fillet	
Type of groove	Square, Single V, Double V, Single bevel, etc.	
Backing material	Steel, Copper, Ceramic	For double-side welding, no backing is needed.
Applicable plate thickness	6mmt ~ 35mmt	Up to 19mmt: through-thickness one-pass welding can be applied; Over 19mmt: Double-side welding. ※ Over 9mmt is recommended.
Targeted welding speed	30cm/min.	± 10cm/min.



# Basic specifications for D-Arc(for ref.)

Welding power source		Note
Max. welding current	650A	—
Duty cycle	100%	—
Secondary-side cable length	Standard 40m	The max. cable length is under examination.
Phase No., Rated frequency	3φ ・ 50・60Hz	—
Rated input voltage	200V±10%	—
Rated input power	43.4kVA 40.2kW	—
Rated load voltage	55V	—
Rated output current range	50～650A	—
Rated output voltage range	12～60V	—
Rated no-load voltage	113V	—

# Basic specifications for D-Arc(for ref.)

Wire feeder (Pulling side)		Note
Max. wire feed rate	100m/min.	A maximum of 30m/min is for welding (with $\phi 1.4$ wire)
Type of motor	AC servomotor	—
Control method	Speed control	Speed control unit is equipped with driver.
Driving system	4 rollers (2 drives)	—
Feeding roller	V-groove roller for steel wire	—
Mass	9kg	—
Structure	Fully covered structure	—
Size (width $\times$ depth $\times$ height $\times$ pass line)	354 $\times$ 369 $\times$ 303 $\times$ 120 mm	—
Wiring	Power circuit for gas solenoid valve. Power circuit for motor. Single wire for encoder.	—

# Basic specifications for D-Arc(for ref.)

Wire feeder (Pushing side , with buffer)		Note
Max. wire feed rate	100m/min	A maximum of 30m/min is for welding (with $\phi 1.4$ wire)
Type of motor	AC servomotor	—
Control method	Speed control	Speed control unit is equipped with driver.
Driving system	4 rollers (2 drives)	—
Feeding roller	V-groove roller for steel wire	—
Mass	17kg	—
Structure	Fully covered structure	—
Buffering mechanism	Wire-curvature adjusting system	The open guide with paired rollers.
Size (width $\times$ depth $\times$ height)	263 $\times$ 580 $\times$ 322mm	—
Wiring	Signal wire for detecting the mass of buffer. Power circuit for motor. Single wire for encoder.	—

# Basic specifications for D-Arc(for ref.)

Torch		Note
Max. welding current	650A	—
Duty cycle	100%	With the 5-kW chiller operated.
Type	Straight	Other types are to be examined.
Outside dimensions	74×65×240mm	Excl. the heat shield
Basic machine mass	Approx. 1.0 kg	—
Cooling system	Water cooling	Chiller is required.

**Please examine the highly-efficient  
thick-plate welding system:  
D-Arc welding.**

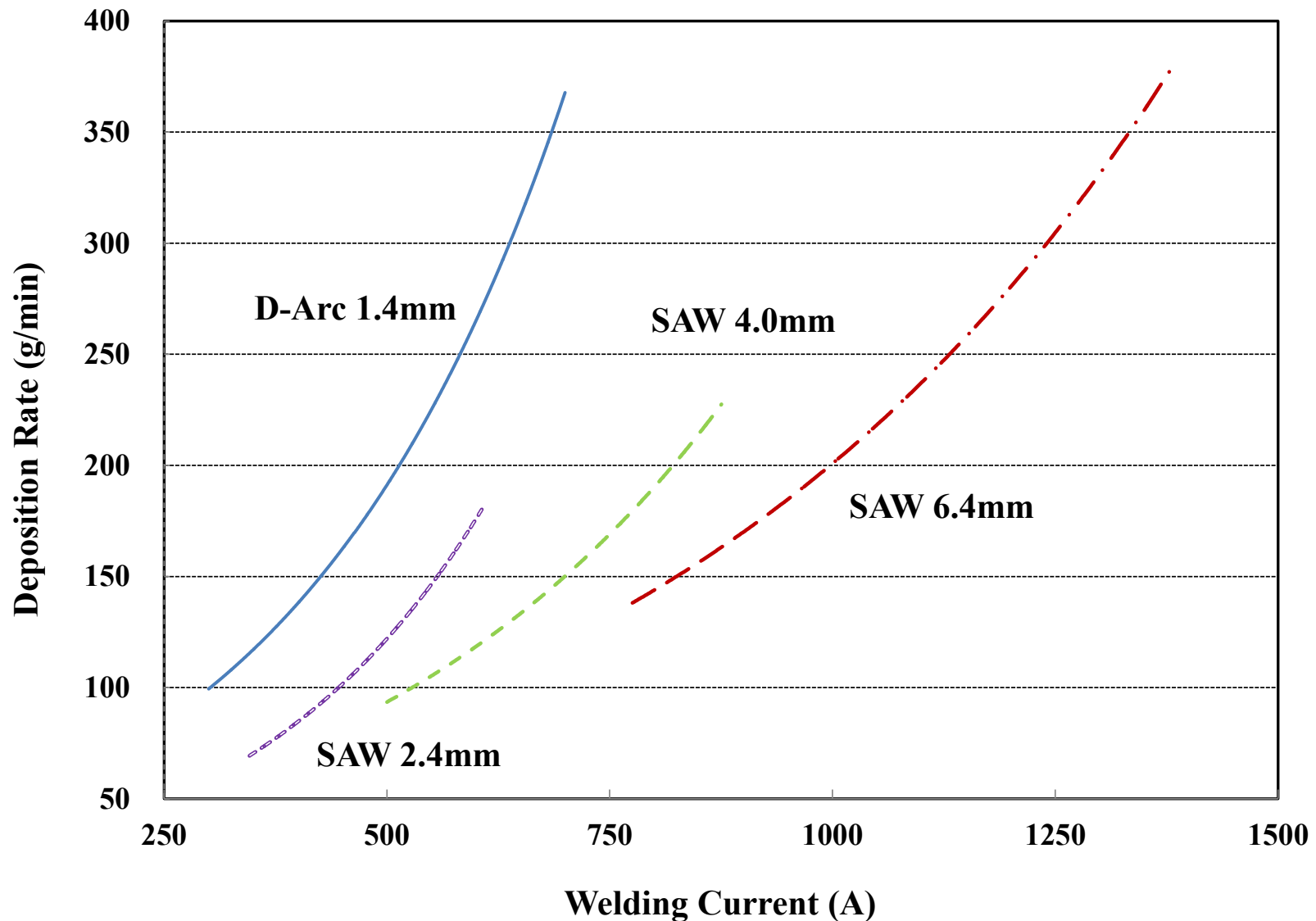
# Benchmark of D-Arc and SAW

	SAW (Single)	SAW (Multi)	D-Arc	Remark (Feature of D-Arc)
Angular Distorsion	2	3	1	Low heat input and 1 pass full penetration welding
Process Flexibility	2	3	1	Single Electrode Welding based on general GMAW
Wire Consumption	3	3	1	Groove less welding is available.
Heat Input	2	3	1	Low heat input per 1 pass
Post Process (Flax Collection)	3	3	1	Collcting flax is not necessary.
Penetration	2	2	1	Deep penetration per 1 pass
Welding Speed	2	1	2	Single electrode welding and almost same welding speed as Single SAW
Deposition Rate	3	1	2	Higher deposition rate at low current range as single electrode welding process
Margin of Welding Condition	1	1	3	Nallow weld bead cannot achive a wide margin of welding condntion.

**1: Superior, 2: Normal, 3: Inferior**

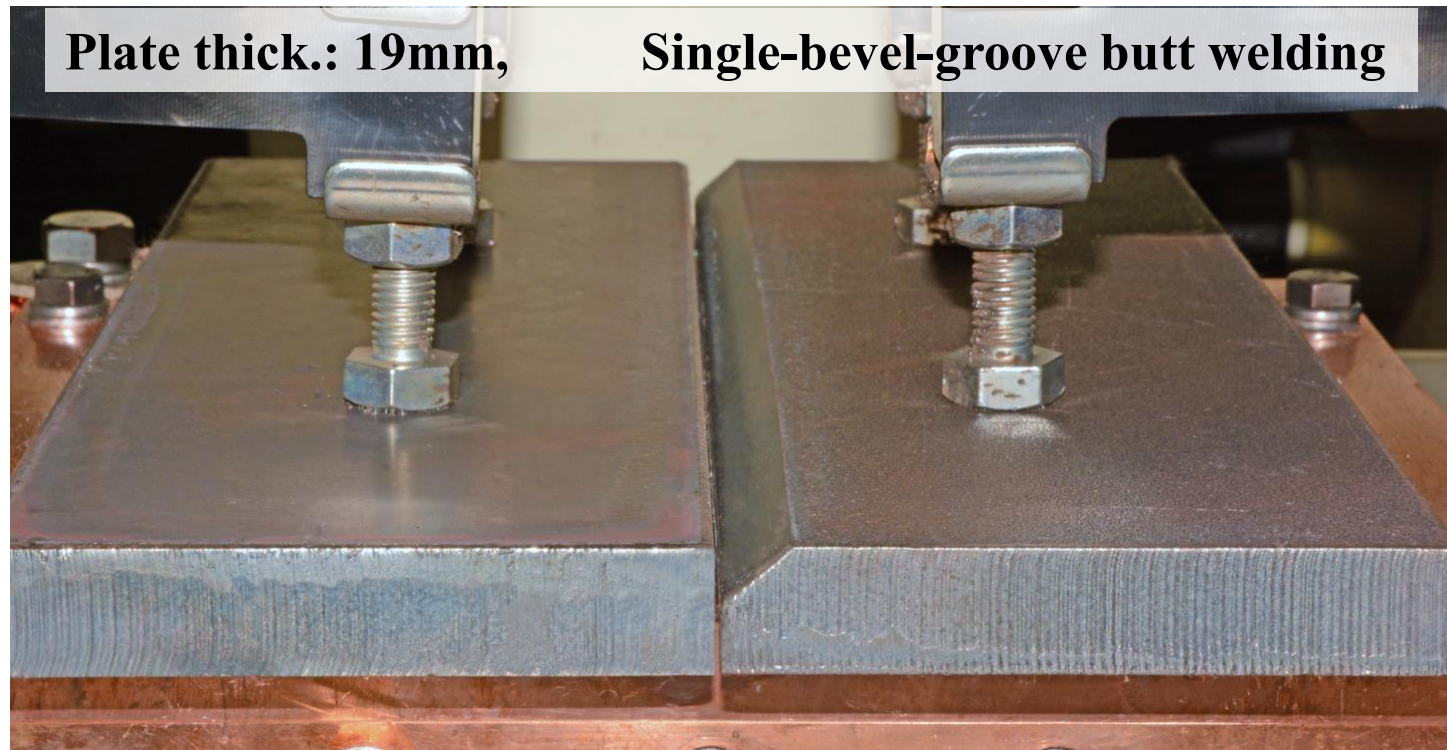


# Comparison of Deposition Rate



# Demonstration at JIWS

## (Japan International Welding Show)



### Welding conditions

<b>Current/voltage</b>	:	<b>650A/45V</b>
Shielding gas	:	CO <sub>2</sub> , 30ℓ/min
Welding speed	:	30cm/min
Wire	:	solid wire, 1.4 mmφ

# Demonstration at JIWS

## (Japan International Welding Show)

