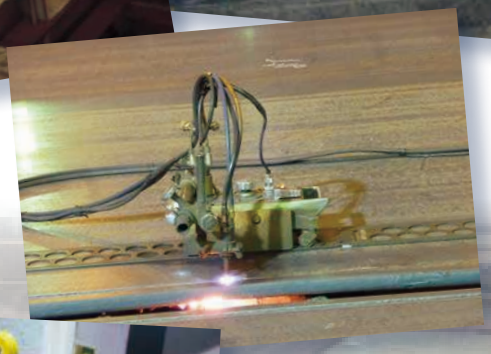
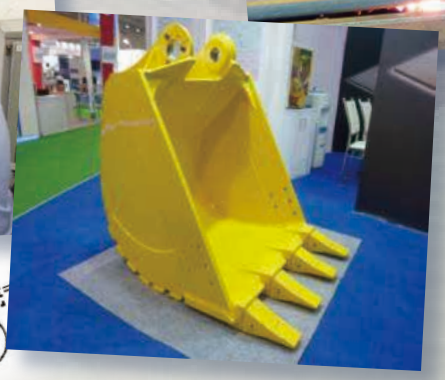
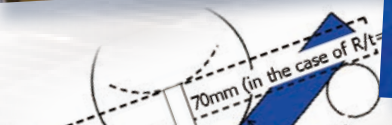
Guidelines for fabrication
JFE's Abrasion-Resistant Steel Plate
EVERHARD™

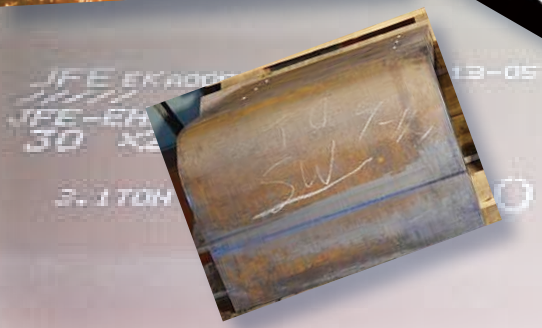
- WELDING -

JFE Steel Corporation









Contents

Guidelines for Fabrication of JFE's Abrasion-Resistant Steel Plate EVERHARD: Welding

In 1955, JFE Steel began manufacturing abrasion-resistant steel plates before any other company. Since that time, these products, trade-named EVERHARD, have been used in a wide range of applications, beginning with industrial machinery and also including civil engineering and construction equipment, mining equipment, and agricultural machinery.

Today, EVERHARD is recognized as an indispensable product that ensures complete customer satisfaction.

This catalog, "Guidelines for fabrication of JFE's Abrasion-Resistant Steel Plates EVERHARD: Welding," was prepared so that all customers can enjoy the outstanding performance of EVERHARD effectively and with full confidence. We hope that the information contained herein will be useful.

Thank you for using EVERHARD, and we look forward to continuing to serve you in the future.

■ Features of EVERHARD

Type	Features	Brand name
C (Standard Series)	General purpose EVERHARD products. Economical alloy design with priority on hardness of steel plates. Strict range of surface hardness and reduced variations in formability.	**EVERHARD-C340**
		EVERHARD-C400
		EVERHARD-C450
		EVERHARD-C500
		EVERHARD-C550
		EVERHARD-C600
C-LE (High Toughness Series)	Guarantees low temperature toughness at -40°C (-40°F). Full line of abrasion-resistant performance up to Brinell hardness 500 grade. Alloy design which considers internal hardness.	**EVERHARD-C400LE**
		EVERHARD-C450LE
		EVERHARD-C500LE
SP (Super Abrasion-Resistant Series)	Product that out-performs even the EVERHARD series. Provides abrasion resistance exceeding Brinell hardness 500 grade.	**EVERHARD-SP**

All information contained in this catalog assumes use of EVERHARD based on a basic understanding of correct welding and within the range of the business experience of JFE Steel Corporation. JFE Steel Corporation cannot accept responsibility for compatibility with individual cases; however, in case of problems, please feel free to consult with this company.

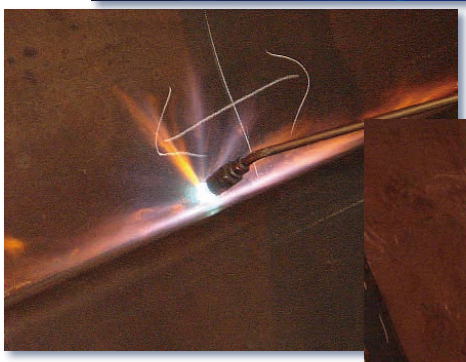
Crack-Free Welds . . . It's Simple with EVERHARD!

Because abrasion-resistant steel plates are hard, which is one of their distinctive features, these materials generally have high cold cracking sensitivity (also called hydrogen-induced or delayed crack sensitivity). However, in EVERHARD, JFE Steel uses the optimum alloy design to improve cold cracking resistance so that users can easily obtain sound, crack-free welds.

This product design technology, which is used in all EVERHARD, is based on a knowledge of metallurgy cultivated over many years by testing of weld joints, and is backed by theoretical analysis.

Cold crackings are caused by diffusible hydrogen. In welding, preheating is normally performed in advance by raising the temperature of the joint in order to drive out diffusible hydrogen into the atmosphere at welding sites, preheating is widely known as a reliable, effective method for preventing cold crackings. However, preheating conditions must be optimized for the steel material which is actually being welded.

This catalog presents use guidelines for the preheating temperature, preheating methods, temperature measurement methods, and related items to enable safe, economical, worry-free use of EVERHARD products. These guidelines also provide useful advice on types of welding work in which the conditions are generally difficult, such as tack welding, root pass welding, etc.



Preheating Temperature Guidelines

The preheating temperature of EVERHARD differs depending on the welding method.

The following table gives guidelines for the minimum preheating temperature corresponding to the welding method, as determined based on the type of EVERHARD, the strength grade (the strength level increases with hardness level), and the plate thickness.

■ Recommended Minimum Preheating Temperature

Brand name	Welding method	Thickness(mm) 10 – 20 – 30 – 40 – 50 – 60 – 70 – 80 – 90 – 101.6
JFE-HITEN780S	SMAW, FCAW	75°C | 100°C | >100°C
	GMAW	Room temperature | 50°C | >50°C
JFE-HITEN780LE	SMAW, FCAW	<100°C | 100°C
	GMAW	Room temperature
EVERHARD-360	SMAW, FCAW	50°C | 75°C | 100°C
	GMAW	Room temperature | 50°C
EVERHARD-400	SMAW, FCAW	75°C | 125°C
	GMAW	Room temperature | 75°C
EVERHARD-500	SMAW, FCAW	125°C | 175°C | 175–200°C
	GMAW	Room temperature | 75°C | 125°C | >125°C
EVERHARD-360A	SMAW, FCAW	100°C | 150°C | >150°C
	GMAW	75°C | 125°C | >125°C
EVERHARD-500A	SMAW, FCAW	125°C | 175°C | 175–200°C
	GMAW	100°C | 150°C | >150°C
EVERHARD-C340	SMAW, FCAW	125°C | >125°C (max.160mm)
	GMAW	75°C | >75°C | 100°C (max.160mm)
EVERHARD-C400	SMAW, FCAW	50°C | 75°C | 100°C | >125°C
	GMAW	Room temperature | 50°C | >75°C
EVERHARD-C450	SMAW, FCAW	75°C | 125°C | >125°C
	GMAW	Room temperature | 75°C | 100°C | >100°C
EVERHARD-C500	SMAW, FCAW	125°C | 175°C | 175–200°C
	GMAW	Room temperature | 75°C | 125°C | >125°C | >150°C
EVERHARD-C550	SMAW, FCAW	200°C
	GMAW	175°C
EVERHARD-C600	SMAW, FCAW	200°C
	GMAW	175°C
EVERHARD-C400LE	SMAW, FCAW	75°C | 100°C | 125°C | >125°C
	GMAW	Room temperature | 75°C | >75°C | 100°C
EVERHARD-C450LE	SMAW, FCAW	75°C | 125°C | >125°C | 200°C
	GMAW	Room temperature | 75°C | 100°C | 175°C
EVERHARD-C500LE	SMAW, FCAW	125°C | 175°C (32mm<) 175–200°C | 200°C
	GMAW	Room temperature | 75°C | 125°C (32mm<) | 175°C
EVERHARD-SP	SMAW, FCAW	100°C | 175°C | 175–200°C
	GMAW	75°C | 175°C

SMAW (Shield metal arc welding): Welding with a coated electrode.
FCAW (Flux cored arc welding) : Welding with a flux cored wire.
GMAW (Gas metal arc welding): Welding methods using a welding wire in combination with a shield gas, for example, carbon dioxide gas shielded arc welding, etc.

Optimum Preheating Methods for EVERHARD

Precautions when welding EVERHARD with different grades

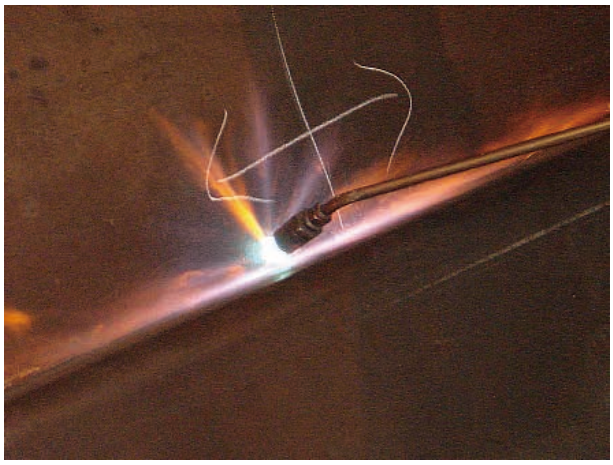
When welding pairs of EVERHARD plates of different grades and/or plate thicknesses, the preheating temperature is basically determined as follows.

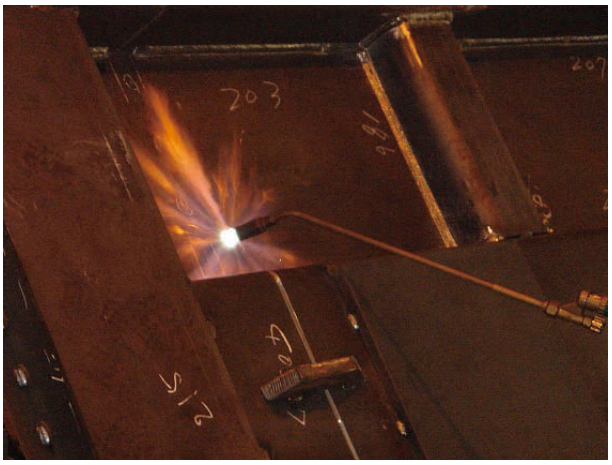
- Select the higher recommended preheating temperature.

■ Optimum preheating method

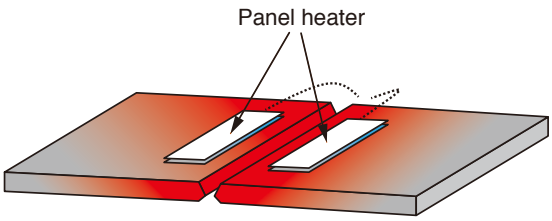
Preheating method

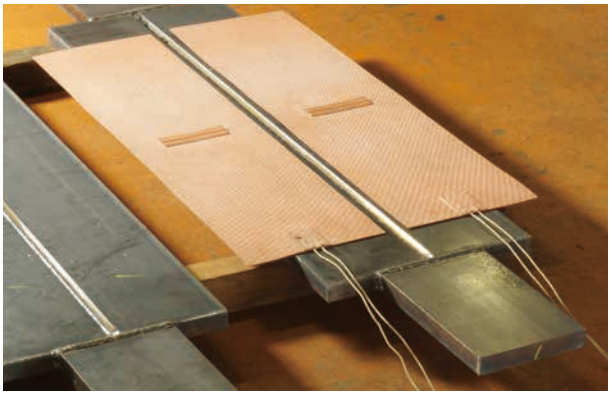
Preheating should be performed with gas or an electric heater. Normally, the heating location is near the weld, but in some cases the entire joint is preheated.





Example of preheating with gas burner





Example of preheating with electric heater (panel heater)

■ Temperature Measurement

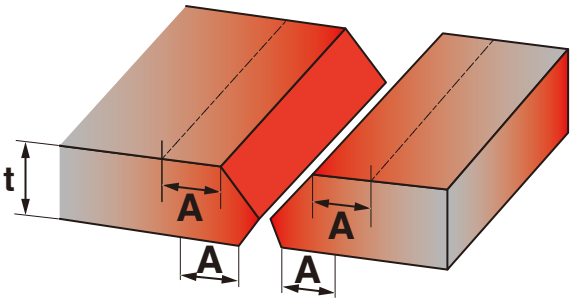
Temperature measurement is extremely important for avoiding preheating failure. Multiple points on the welding line should be checked whether each point has achieved the specified temperature. If possible, check not only the front side, but also the back side.

■ Guidelines for Temperature Measurement

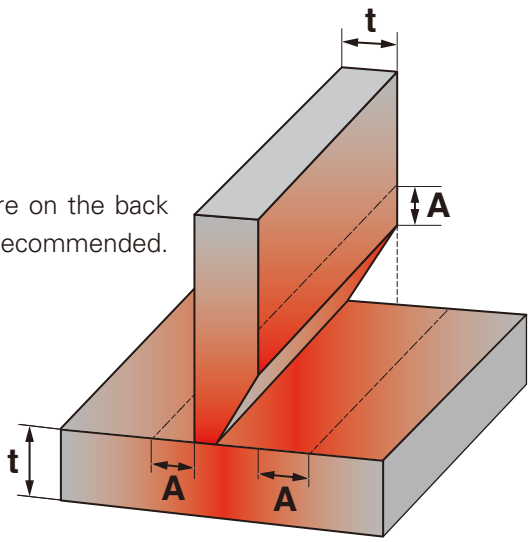
Measurement position
(See schematic diagram)

t≤50: A=4×t≤50
t>50: A=75
(Unit: mm)

* To be more certain, measurement of the temperature on the back side of the weld (opposite side of the heated side) is recommended.



Butt joint



T joint (fillet welding)

Timing: Although only the surface temperature is measured, what is important is the internal temperature of the plate. The optimum timing of temperature measurement is when the plate temperature has become stable after the temperature rise has slowed. As a reference, for 25mm thick plate, it takes about 2 minutes of which temperature becomes stable.

Measuring devices: The following temperature measuring devices are commercially available and can be used.

- Temperature-indicating crayon (also called temperature chalk) or paint (also called thermopaint, heat sensitive paint, etc.)
- Thermocouple
- Thermometer (can be either contact or noncontact type)

Example of temperature measurement by using a noncontact type thermometer

Example of temperature-indicating crayon
Temp Stick™, manufactured by Caltech Engineering Services (http://www.caltechindia.com/TempSticks.htm)

What are Cold Crackings?

Cold crackings are cracks that occur after a weld has cooled to less than 150°C. They can occur in the weld metal, the heat affected zone (HAZ), or both. As a distinctive feature, in almost all cases, cold crackings are so-called delayed fractures, in which the crack occurs some time after welding.

What are the causes of cold crackings?

The factors that cause cold crackings can be divided into the three shown below. Cold crackings occur when these factors simultaneously satisfy a certain condition. In other words, it is necessary to control these three factors in order to prevent cold crackings. Preheating, as described previously, is effective for reducing the hydrogen content.

Hydrogen content (H) of the welding consumables:	In almost all cases, the cause of elevated hydrogen is moisture absorption by the welding consumables.
Hardenability of steel material:	Known to be closely related to the weld crack sensitivity composition (P_{CM}) of steel.
Restraint stress:	Proportional to the plate thickness (t) of the joint.

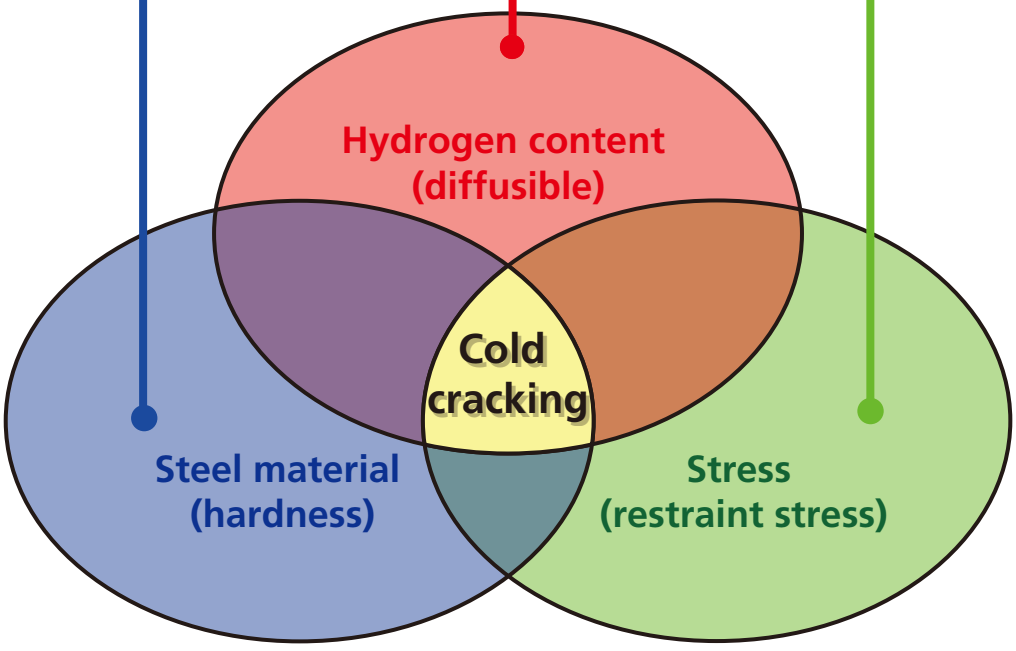
How can we determine the optimum preheating temperature (T_0)?

As one method of controlling the three factors mentioned above and determining the necessary preheating temperature for preventing cold crackings, the following relational expression can be used. This expression was obtained experimentally.

Recommended minimum preheating temperature is partially determined by using this expression.

$$T_0 \propto P_{CM} + \frac{H}{60} + \frac{t}{600}$$

P_{CM} = C+Si/30+(Mn+Cu+Cr)/20+Ni/60 +Mo/15 +V/10+5B (%)
H: cc/100gFe (weld metal)
t : mm



Example of control of factors causing cold crackings

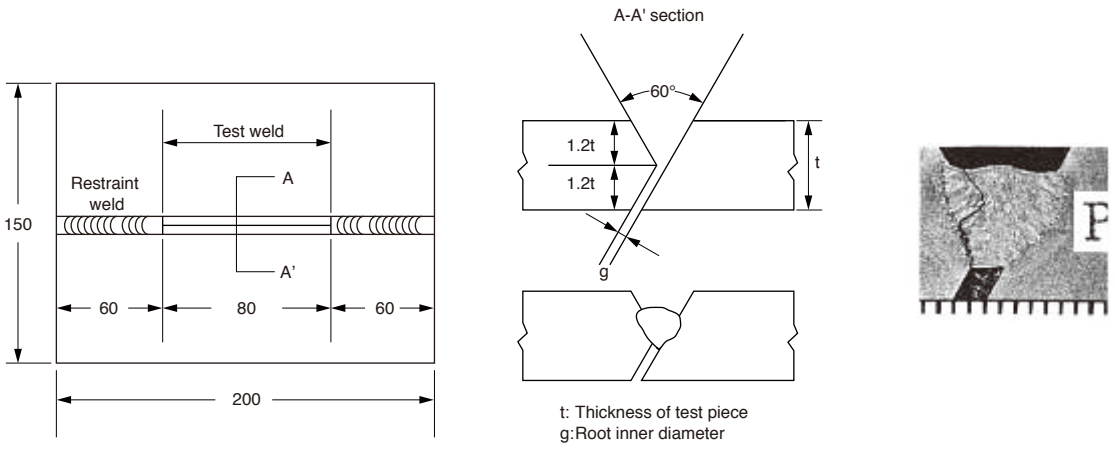
Due to the high hardness and strength of EVERHARD, its cold cracking sensitivity is also higher than that of general steel materials. To prevent cold crackings when welding EVERHARD, the following advance precautions are indispensable.

Factor	Precaution		Remarks
Diffusible hydrogen	Use of low hydrogen (or ultra-low hydrogen) welding consumables (coating material, flux)		In accordance with the standard of the welding consumable (AWS, JIS).
	Proper drying	Drying of welding consumables (coating material, flux)	Example) 350-400°C × 1 hour
		Prevention of condensation	Temperature of the materials being welded should be at least 20°C or higher.
	Cleaning of joint		Completely remove rust and oil.
Hardness of weld metal and HAZ	Selection of low carbon equivalent steel		Use low P_{CM} design EVERHARD.
	Stable welding		Short bead welding is not permissible. Tack beads must be removed before final welding.
Residual or restraint stress	Joint gap control		Groove gap should be less than 3 mm.

Hint!

■ Y-Groove Weld Crack Test (JIS Z 3158)

The preheating temperature guidelines recommended by JFE Steel were developed based on experience and data in connection with the y-groove weld crack test, which is specified in JIS Z 3158. Although this is widely known, because the restraint level in this test method is higher than that of actual welded structural joints, the preheating temperature obtained by this method is strict (higher, i.e., safer). In case of problems in actual preheating using these guidelines, please contact JFE Steel.



Test piece and cross section in JIS Z 3158

Example of crack

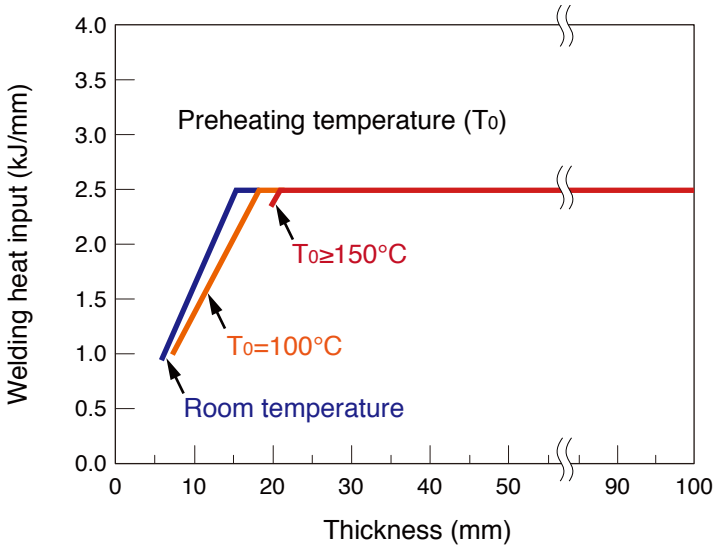
Welding Heat Input for EVERHARD

In order to satisfy mechanical performance requirements and obtain sound welds with minimal thermal stress efficiently as planned, it is important to use the proper welding heat input in welding work.

■ Maximum heat input (recommended)

The following figure shows the maximum welding heat input for maintaining weld soundness as far as possible.

Although somewhat different depending on the preheating temperature (T_0) of steel plates, the maximum welding heat input increases linearly with the thickness of the plate, and becomes constant when the thickness exceeds about 20 mm. For actual welding, JFE Steel recommends use of a smaller heat input than the line shown in this figure.



■ Calculation of welding heat input

Welding heat input is calculated from the following equation.

$$H = \frac{I \times V}{v} \times 0.06$$

H : Welding heat input (kJ/cm)
I : Welding current (A)
V : Welding voltage (V)
v : Welding speed (cm/min)

■ Related Precautions!

Particularly in multilayer welding, softening may occur in the heat affected zone (HAZ). Therefore, when performing multilayer welding, wait until the temperature of the previous weld bead has decreased to less than about 250°C. At this time, the temperature should be measured at a point within 10 mm from the previous bead.

Short bead welding and the type of unstable (unsteady) welding called spot welding not only cause fatal welding defects, but also result in larger-than-expected hardening of the microstructure accompanying the rapid cooling phenomenon, and this increases the risk of cold crackings. In welding in a stable, steady condition (uniform cooling), use a bead length of more than 50 mm.

Suitable Welding Consumables for EVERHARD

General abrasion-resistant steel plates, including EVERHARD, are especially designed to obtain high hardness to improve abrasion resistance, if general commercial welding materials (welding consumables) are used in welding, the hardness of the weld may be low in comparison with the abrasion-resistant steel base material. This condition, in which the hardness of the weld is lower than that of the base material (abrasion-resistant steel) is called "under-matching." Welds of buildings, etc. are designed as over-matching, i.e., the hardness of the weld is higher than that of the base material, so that cracks will not originate from the welds, but this is difficult with abrasion-resistant steels. Thus, care is necessary when welding abrasion-resistant steels. On the other hand, because the cold cracking sensitivity of abrasion-resistant steels is high in comparison with general steel materials, we recommend under-matched welding, in which generation of stress on the base material side is difficult, from the viewpoint of cracking during welding.

The next point is the actual selection of the welding consumable. From the viewpoint of prevention of cold crackings, we recommend the use of either a low hydrogen type or an ultra-low hydrogen type of welding consumable. In the case of buckets, vessels and other structural parts where weld strength is critical, the welding consumable should be selected in accordance with the strength design of the welded joint. In welds of liner plates and similar parts in which weld strength is not particularly necessary, we recommend selection of a welding consumable with the lowest possible strength in comparison with the base material in order to prevent cold crackings.

The following table gives examples of the applicable welding consumables for use with EVERHARD.

■ Examples of Applicable Coated Electrodes

Grade	Shield metal arc welding (SMAW)		
	KOBELCO brand name	AWS*	Others
400MPa	LB-47A	E7016	LINCOLN ELECTRIC (USA) METRODE (UK) HYUNDAI WELDING (KOREA) ESAB (SWEDEN) OERLIKON (GERMANY) BOEHLER (GERMANY)
490MPa	LB-52 LB-52UL		
590MPa	LB-62 LB-62UL	E9016-G	
780MPa	LB-116 LB-80UL	E11016-G	

*AWS: The American Welding Society

■ Examples of Applicable Flux Cored Wires

Grade	Flux cored arc welding (FCAW)		
	KOBELCO brand name	AWS*	Others
400-490MPa	DW-100, MX-100	E70T-1C	LINCOLN ELECTRIC (USA) HYUNDAI WELDING (KOREA) ESAB (SWEDEN) OERLIKON (GERMANY) BOEHLER (GERMANY)
590MPa	DW-60, MX-60	E81T1-Ni1C	

*AWS: The American Welding Society

■ Examples of Applicable Solid Wires

Grade	Gas metal arc welding (GMAW)		
	KOBELCO brand name	AWS*	Others
400-490MPa	MG-50 MGS-50	ER70S-G	LINCOLN ELECTRIC (USA) METRODE (UK) HYUNDAI WELDING (KOREA) ESAB (SWEDEN) OERLIKON (GERMANY) BOEHLER (GERMANY)
590MPa	MG-60	ER80S-G	
	MGS-63B	ER90S-G	
780MPa	MGS-80	ER110S-G	

*AWS: The American Welding Society

Welding Shield Gas for EVERHARD

Welding of EVERHARD does not require any change in the condition of shield gas. The gas type, flow rate, etc. recommended for the welding consumable being used can also be applied to EVERHARD without change.

Examples of the shield gases applied with KOBELCO's GMAW welding consumables, which are recommended for welding of EVERHARD, are shown in the following table.

■ Examples of Shield Gases applied with KOBELCO GMAW Welding Consumables

Grade	Gas metal arc welding (GMAW)		
	KOBELCO brand name	Shield gas	AWS* grade
400-490MPa	MG-50	CO_2	ER70S-G
	MGS-50	Ar+CO_2	
590MPa	MG-60	CO_2	ER80S-G ER90S-G
	MGS-63B	Ar+CO_2	
780MPa	MGS-80	Ar+CO_2	ER110S-G

* AWS: The American Welding Society

Gas metal arc welding (GMAW): Example of carbon dioxide gas shielded arc welding

Welding Start/Final Ends and Gap

In general, defects such as blowholes and lack of penetration, craters and flowing-down of the weld metal occur easily at the start and final ends of welding. This is because welding is unstable (unsteady condition) at the start and final ends. At the start/final ends of welds, the following measures are effective for preventing these types of welding defects. These measures are particularly recommended when welding EVERHARD.

■ Measures for start/final end of welding

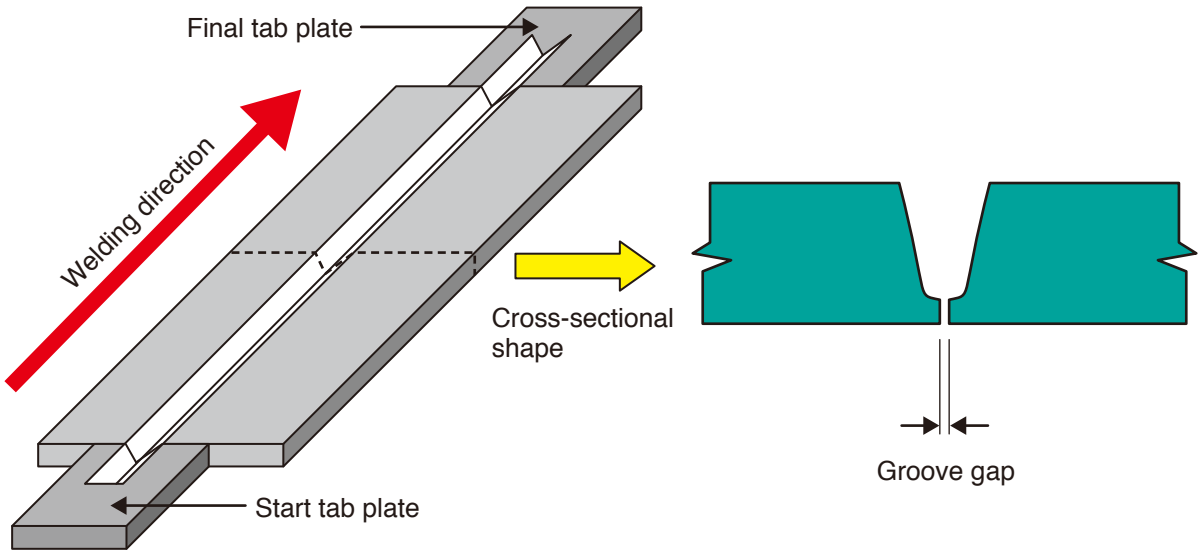
Normally, rectangular steel plates are attached to the start and final ends of welds as welding tab plates. Care should be taken to match the tab plate center line with the welding seam. As shown at the lower left, welding begins on the start tab plate attached to the start end and ends on the final tab plate. Care should be used so that the length of the beads on the tab plates is sufficient to enable stable welding (for example, 50 mm or more).

A sound weld can be obtained by removing the two tab plates after welding is finished.

■ Groove Gap

The groove gap of welded joints is a critical control item for preventing weld defects. Normally, the gap of the grooves in butt and filet welding should be less than 3 mm. The groove gap is shown schematically at the lower right.

As mentioned previously, this control is also effective for preventing cold crackings.



Welding tab plates (start tab plate and final tab plate)

Gap of a butt-welded joint as seen at the groove cross section

Hardfacing of EVERHARD

Hardfacing of EVERHARD is possible. However, when applying hardfacing, the following precautions are generally necessary.

(Care is required, as EVERHARD is intrinsically hard, and applying an even harder hardfacing may result in easier cracking than normal.)

1) Preparation of base material (EVERHARD)

To prevent blowholes in the hard-faced material, remove all rust, oil, sand and other foreign matters completely.

2) Temperature control

To prevent weld cracks, not only preheating, but also interpass temperature control and temperature control in post weld heat treatment are important. Please note the key points in the above-mentioned guidelines for temperature measurement of EVERHARD.

3) Underlaying and dilution control

One effective method for securing the required hardness of the hardfacing layer is underlaying. For best results, in this case, JFE Steel recommends the use of a mild steel grade low hydrogen welding consumable or an authentic welding consumable. Multilayer hardfacing is also a possible option.

4) Strain control

Welding procedure that forms a symmetrical weld bead or intermittent welding, by appropriately using restraint, is also effective for minimizing welding distortion.

Post Weld Heat Treatment of EVERHARD

In welding of pressure vessels, post weld heat treatment (PWHT) is generally performed to remove residual stress. However, this practice is not recommended to EVERHARD because PWHT will seriously affect the mechanical properties and abrasion resistance of EVERHARD.

In cases where PWHT is unavoidably necessary, please be sure to consult with JFE Steel.

Primer Treatment of EVERHARD

JFE Steel also provides the EVERHARD with primer (paint) treatment upon request.

As a shop primer, JFE normally uses SD ZINC 1000HA (S) manufactured by ALESCO (Kansai Paint Co., Ltd.). This primer consists of modified alkyl silicate binder and zinc (Zn) powder with improved performance. It displays excellent cutting properties and weldability, and also minimizes generation of pitting and blowholes during CO_2 gas shielded arc welding. It is also possible to select SD ZINC 1000 JLEC™ with enhanced corrosion resistance and laser cuttability.

In order to provide this performance, the thickness of the primer layer is strictly controlled within the optimum range.

Typical appearance of primer-treated Standard Series plate (EVERHARD-C500 (JFE-EH-C500))

When performing cutting or welding work, be sure to use proper ventilation and wear a protective mask.

Storage

EVERHARD plates should be stored so as to avoid bending and twisting. Use waterproof sheets to prevent rust and pitting due to corrosion, which can cause cracking. When using a waterproof sheet, ventilate occasionally to reduce humidity under the sheet.

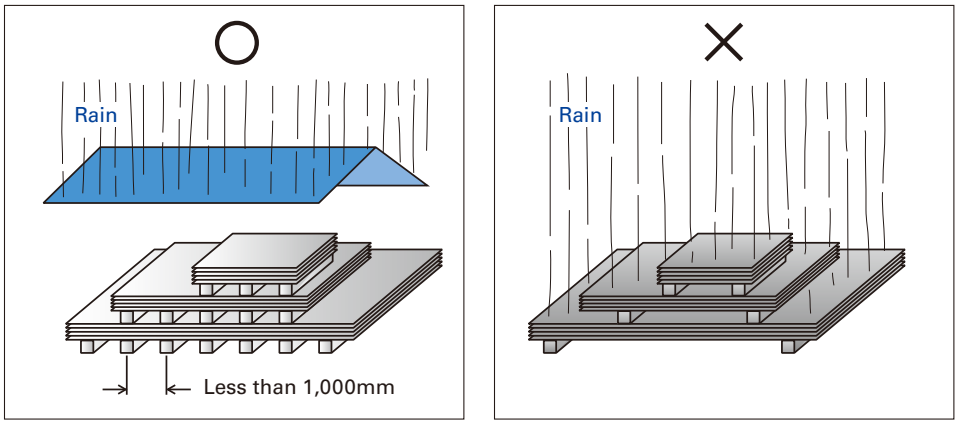


Fig. Recommended storage method

Cat.No.C1E-012-04

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