Tokyo Steel Manufacturing Co.,Ltd.

CARBONMINUS × UPCYCLING
EcoVision2050

Technology of Hot Rolled Mild Steel Sheets & Steel Strips

(Formability, Fatigue property and Spot weldability of SPHC Steel)

Steel Sheets
Hot Rolled Coils

2022.06.01

Contents

Hot Rolled Mild Steel Sheets & Steel Strips

TOKYO STEEL
MANUFACTURING CO.,LTD.

2022.06.01

① Introduction

Tokyo Steel's Views to Global Warming

Source: Home Page, Tokyo Steel Manufacturing Co., Ltd.

In 1997, the Kyoto Protocol became the world's first international agreement on the issue, producing commitments by principally European countries and Japan to reduce their CO_2 emissions in 2012 by about 5% compared with 1990. Further discussions have been continued at the summits and international conferences, trying to determine additional and stricter targets, and to fashion a system in which all nations can participate.

Taking action against global warming is the responsibility of current generations. We must act now to reduce CO_2 emissions and develop the alternatives for fossil fuels to preserve the Earth's environment.

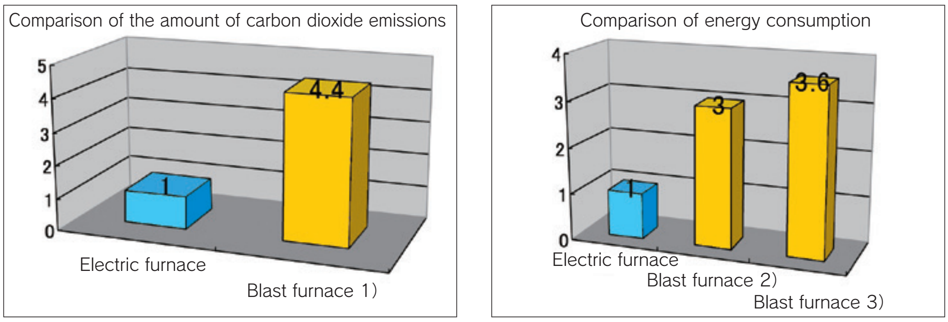
In Japan, the CO_2 emissions of the steel industry account for a little over 14% of the total (FY2008), the highest proportion among all the industries. Since steel is essential for the society to achieve industrial development, there is a clear need to find a way to reduce CO_2 emissions in manufacturing steel.

There is a big difference in CO_2 volume between two methods being used to manufacture steel; making one ton of steel through a blast furnace method using iron ore and coal as its main feeds emits two tons of CO_2 compared with less than 0.5 tons by an electric furnace method which is making steel through recycling of steel scrap. For manufacturing exactly the same type of steel, the CO_2 emissions from an electric furnace mill are one fourth of those by a blast furnace mill.

In 1995, we brought the Utsunomiya works on stream, establishing basically almost the same product lineup and capacity that Tokyo Steel has today. During the 15 years since FY1995, we have got about a 440-thousand-ton yearly average reduction in CO_2 emissions over the 15 years through replacing a supply of steel products which had been produced by the blast furnace mills. Therefore, we consider that Tokyo Steel has actually achieved a reduction in CO_2 emissions equivalent to 35% of its FY1990 CO_2 emissions, which is evidently a huge reduction compared With the 5% target set for Japan as a whole under the Kyoto Protocol.

When we consider a substantial reduction of CO_2 emissions, recycling of steel scrap should be further promoted in Japan.

The Okayama Plant of Tokyo Steel started the production of hot-rolled mild steel strips from electric furnace steel by introducing the leading-edge DC electric furnace-hot strip mill in October 1991. We also introduced the continuous pickling line in 1995, cold rolling mill and surface treatment line in 1997 and leveller/shear line in 2004 to address the current manufacture of hot-rolled mild steel sheets and strips, pickled steel sheets and strips, hot-dip galvanized steel strips. By studying and developing the technology to effectively utilize the tramp elements (traveling elements) such as Cu which increase in volume as the number of recycling count grows while utilizing the accumulated operation know-how, we provide high-quality and environmentally friendly electric furnace steel materials that suit the needs in a wide range of fields including industrial machines, home appliances and automobiles.

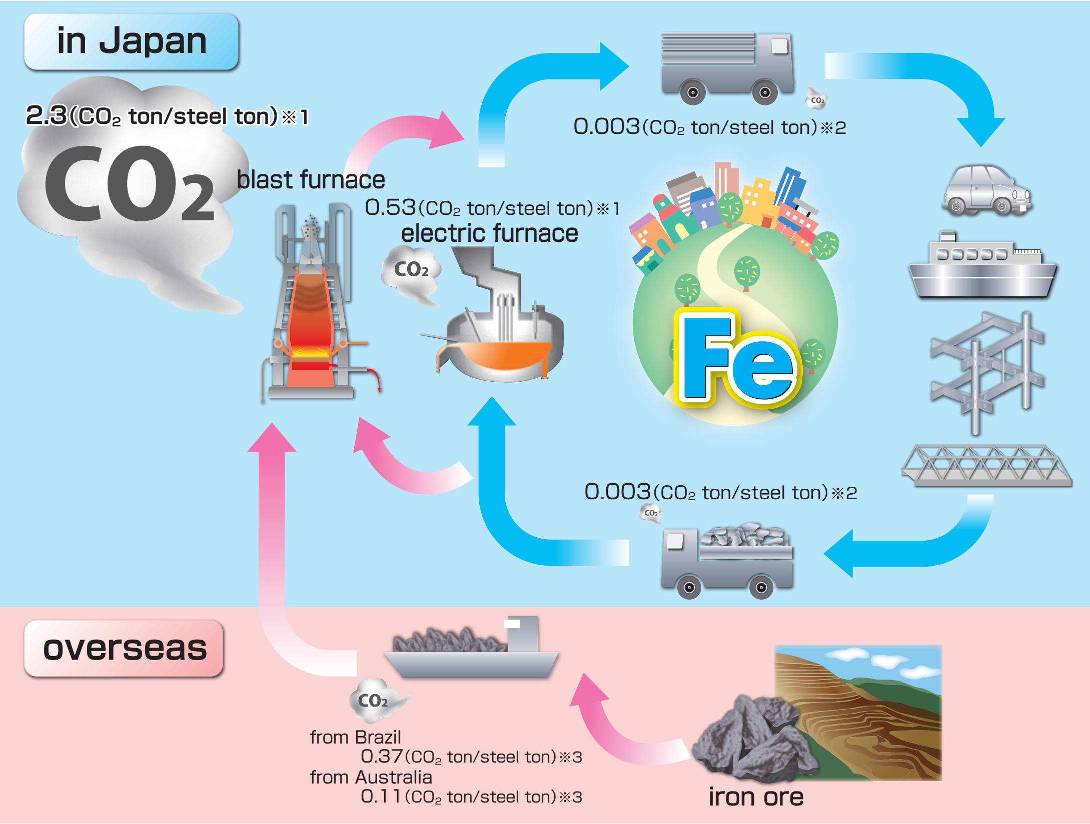


Comparison of the amount of carbon dioxide emissions

Comparison of energy consumption

References:
1) Makoto Nishino: "Theoretical evaluation of CO_2 emission by integrated steelmakers", Ferrum, Vol.3, No.1 (1998),p.23
2) Environmental Affairs Group, the Japan Iron and Steel Federation: Efforts against environmental problems in steel manufacture industry, Tekkokai (1992), p.24
3) Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry and the Japan Iron and Steel Federation: Energy evaluation study for use of steel products seen from LCA viewpoint

Fig.1 Amount of carbon dioxide emissions and amount of energy consumption under production



References:

※1 Makoto Nishino: "Theoretical evaluation of CO_2 emission by integrated steelmakers", Ferrum, Vol.3, No.1 (1998), p.23.

※2 In case of 50km land transportation after Ministry of Economy, Trade and Industry and Ministry of Land, Infrastructure, Transport and Tourism: "A guideline for a calculation method on CO_2 emissions in transport sector" (http://www.enecho.meti.go.jp/policy/images/060518pamph.pdf)(2010), p.6.

※3 Ship & Ocean Foundation: "A report on research concerning the reduction of CO_2 emission from vessels" August 2000 (assuming that the iron content of iron ore is 60%, Japanese version p.92).

Fig.2 Amount of CO_2 emissions per one ton of steel (products) accompanying recycles of steel

❷ Characteristics of manufacturing process

Hot rolled mild steel sheets and steel strips by Tokyo Steel are produced by using:

1) A large direct current electric furnace with eccentric bottom tapping (EBT)
   - Steel scrap is melted homogenously and efficiently by optimized arrangement of electrodes.
   - Low inclusion and low nitrogen content of steel are obtained by EBT

     While minimizing the mixture of impurities such as inclusion by EBT, we reduce the mixture of nitrogen to manufacture clean liquid steel.
2) Steel refining at ladle furnace
   - Homogeneity of chemical compositions is obtained by stirring Ar-bubbling.
   - Quality of continuously cast slab is stabilized by temperature control.
3) Continuous casting
   - Reduction in inclusion and improvement of internal quality of slab is obtained by complete insulating from the air.
4) Hot strip mill
   - Improvement in surface quality by ultrahigh-pressure water descaling

     We set up the descalers at the entrance and the exit side of a rougher mill and also at the entrance side of a finishing tandem mill. They remove the scales generated on the rolling material surface.
   - Improvement of the precision of thickness of steel sheets by a coil box

     We wind steel plates before entering a finishing mill and equalize the temperature all over the materials in order to reduce the disturbance due to temperature difference and improve the sheet thickness precision.
   - Microstructural optimization of steels by TMCP (Thermo-Mechanical Control Process)

     We can obtain the required microstructures and mechanical properties by controlling the cooling patterns over a run-out table.

As described above, we can apply the most suitable conditions to production by using various high advanced steel making facilities and hot strip mill. And we can manufacture high quality steel products with excellent mechanical property, formability, and weldability.

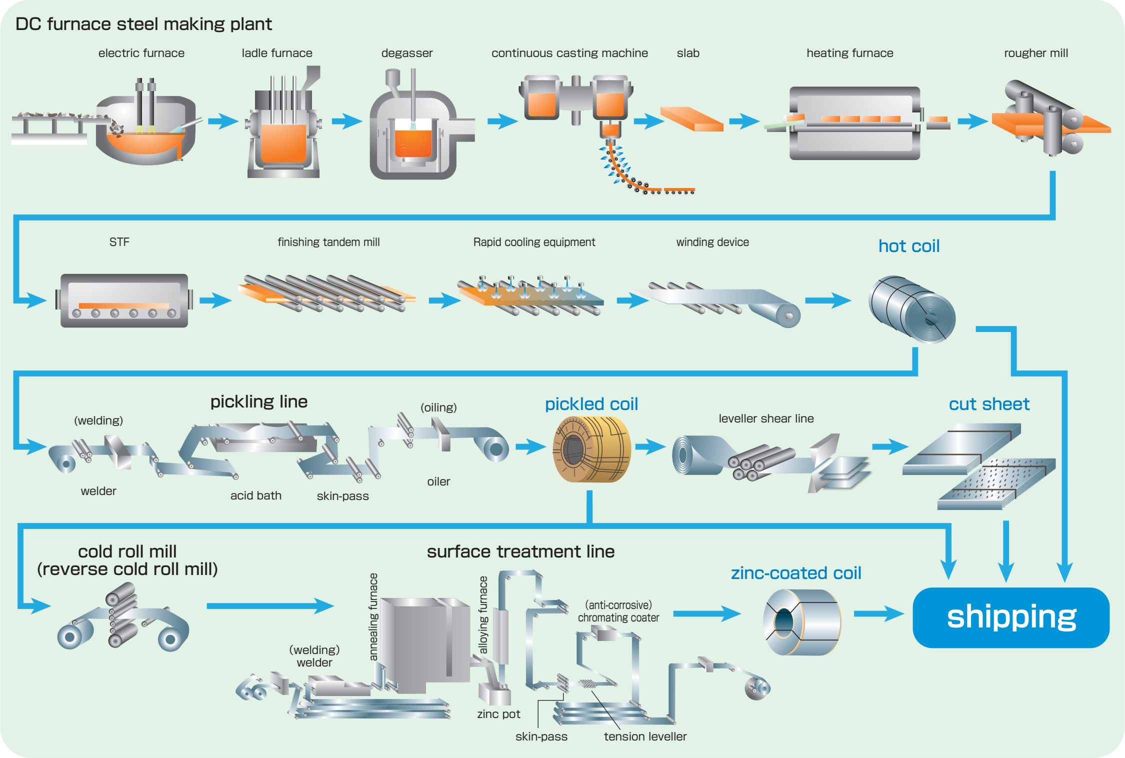


Fig.3 Process drawing (Flowchart)

❸ Data of quality

This document introduces the characteristics of SPHC steel including the formability, fatigue property and spot weldability.

3.1. Chemical composition and mechanical property

The chemical composition and mechanical properties of the samples are listed in Table 1 and Table 2. Comparing steel strips or steel sheets with steel plates, they are produced with lower C and Si contents than steel plates. In addition, when we focus on the metal microstructure, they have uniform crystal grain diameters in both thickness and width with little inclusions thanks to the steel making, rolling and cooling processes (Photo1).

Table1　Chemical composition

	chemical composition (mass %)										
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V	N	Ceq
thickness 1.6mm	0.01	0.02	0.14	0.013	0.001	0.23	0.09	0.12	0.03	0.001	0.0037	0.07

$$Ceq(\%) = C + \frac{Mn}{6} + \frac{Si}{24} + \frac{Ni}{40} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{14}$$

Table2　Mechanical properties

	yield strength (N/mm^2)	tensile strength (N/mm^2)	elongation (%)	n-value	r-value
thickness 1.6mm	284	356	44.2	0.227	0.93

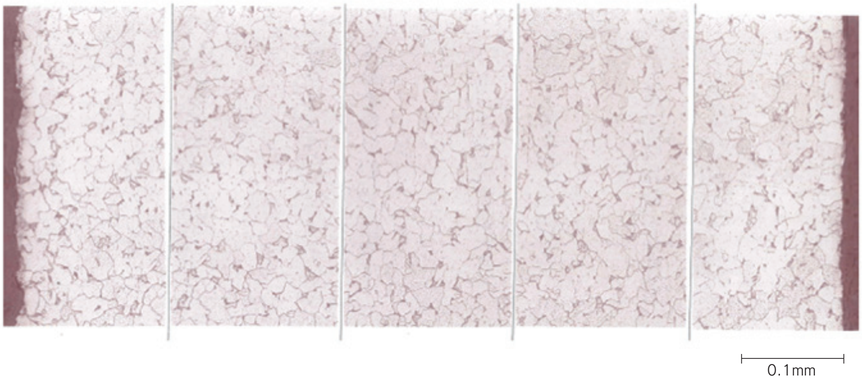


Photo1　Optical microstructure

3.2. Press Formability(CCV, LHER, Erichsen, and LDR)

The deformation modes in press forming can be classified as deep drawing, bulging, stretch-flanging and bending as shown in Fig.4. The relationship as shown in Table 3 is observed between these deformation modes and the characteristic values of the material.

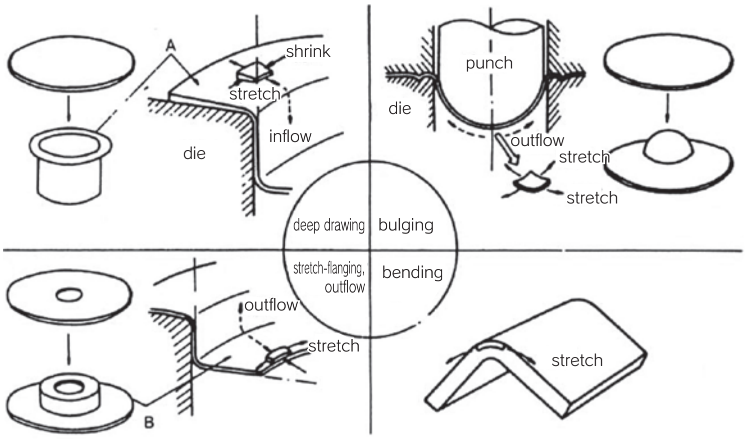


Fig.4 Schematic illustration of typical defomation

Table3 Characteristic value and test method

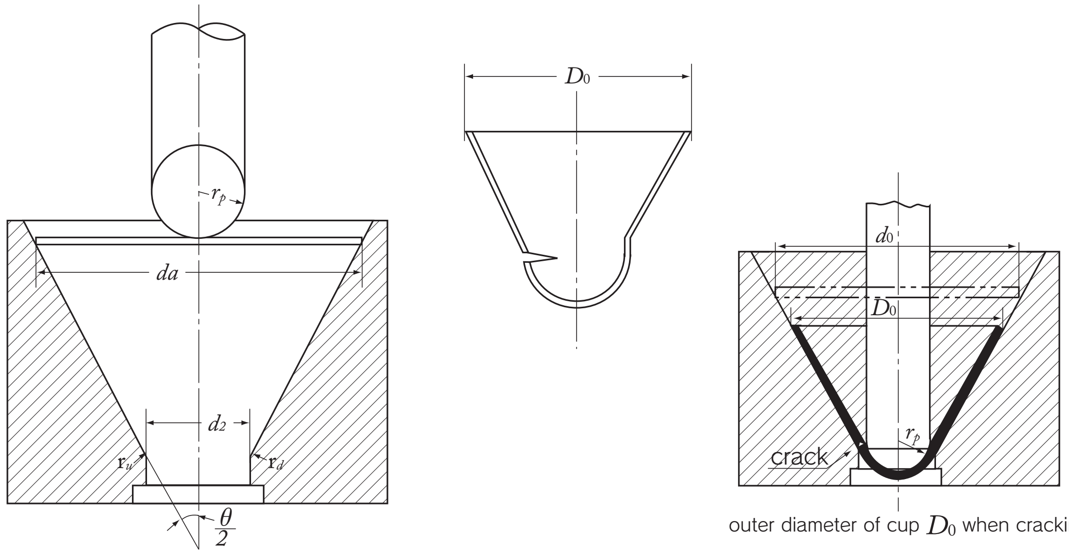
Characteristic value	Test method	Points
n value	Tensile test	**Drawability** is improved as the value of work hardening coefficient (n-value) is larger because elongation until localized shrinkage occurs is large. It becomes the indicator for whether the material excels in **bulging**/strain uniformity during pressing. The general value for mild steels in market ranges about 0.15 to 0.25.
r value	Tensile test	The ratio value between sheet width strain and sheet thickness strain which is also called plastic anisotropy or Lankford value, and **deep drawability** is higher as this value is larger. The general value for hot rolled sheets and strips in market ranges 0.80 to 0.95.
Conical cup value (CCV)	Conical cup test	A test combining **deep drawing** and **bulging** deformation (composite formability test).
Limiting hole expansion ratio (LHER)	Hole expanding test	One of the **stretch-flanging** tests to test how easy it is to form with tensile deformation of the flange edge and inside as the deformation mode.
Erichsen value	Erichsen test	The amount of stretching when the center of the sheet is pushed up with a punch with the edges held and the sheet suffers fracture is called the Erichsen value and it is an indicator for evaluating the **bulging formability** (forming with biaxial tension deformation).
Limiting drawing ratio (LDR)	Deep drawability test	A method for **deep drawing (shrink-flanging deformation) property testing** and it is an indicator for how easy it is to form by drawing into the die hole by punching force with flange deformation by tension and compression.
Bendability	Bend test	A test to evaluate how easy it is to **form by bending** with approximate plane strain deformation and crack generation is checked after carrying out specified radius bending.

For press formability test, we have carried out conical cup test, hole expansion test, Erichsen test, and deep drawing test. Table 4 and Tables 5 to 8 list the conditions for each test and the test results, respectively. The SPHC steel by Tokyo Steel exhibits the excellent workability including 203% hole expansion ratio and 2.20% limiting drawing ratio.

Table4　Conditions for tests

test item	method	test piece	lubricant	work speed	blank holding force
Conical cup	JIS Z 2243	27 model　ϕ78	machining oil	10mm/min	none
hole expansion	JFS T 1001(1996)	100×100 (die inside diameter ϕ10.4mm)	no lubricant	20mm/min	9.0ton
Erichsen	JIS Z 2247	100×100mm	graphite grease	10mm/min	1.0ton
deep drawing	–	ϕ78～92mm	Daphne SK	25mm/min	2.0ton

Conical cup test



outer diameter of cup D_0 when cracking

form into a conical cup shape until the bottom breaks

Fig.5 Schematic showing tool and specimen dimensions for the conical cup test

Table5　Results of conical cup test

sample	max (mm)	min (mm)	CCV (mm)	average (mm)
1	61.15	60.82	60.99	61.0
2	61.07	60.82	60.85	
3	61.14	61.06	61.10	

Hole expanding test

There are two kinds for the punch: conical and cylindrical types

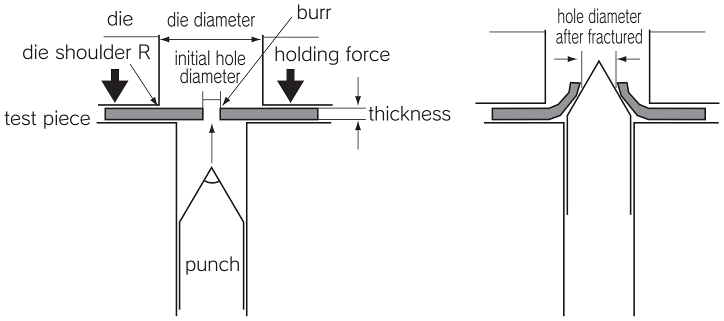


Fig.6 Conical type

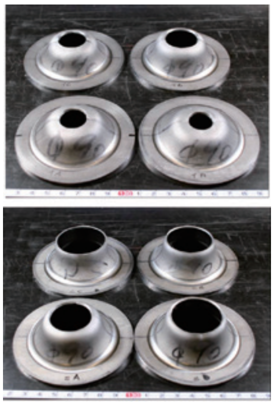


Photo2 Test pieces after hole expansion test (cylindrical type)

Table6 Results of hole expansion test (Comparison with other companies)

	limiting hole expansion ratio (%)	average (%)
Our material	210.4 , 206.5 , 192.4	203.1
Blast furnace A corporation	175.9 , 115.0 , 139.2	143.4
Blast furnace B corporation	155.1 , 139.4 , 138.7	144.4
Blast furnace C corporation	152.9 , 124.0 , 161.0	146.0

Erichsen test

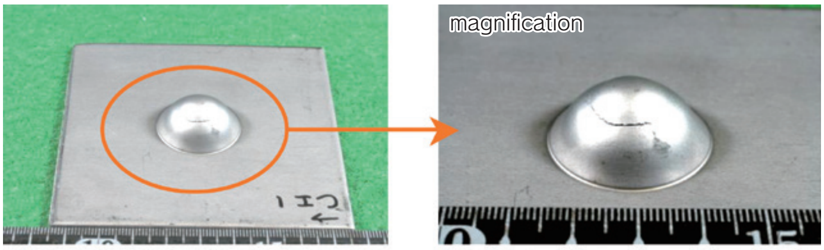


Photo3 Test piece after Erichsen test

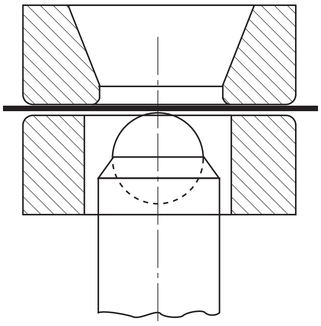


Fig.7 Schematic illustration of erichsen test tool shape

Table7 Results of Erichsen test

sample	height (mm)	average (mm)
1	15.5	15.6
2	15.2	
3	16.0	

Deep drawing test

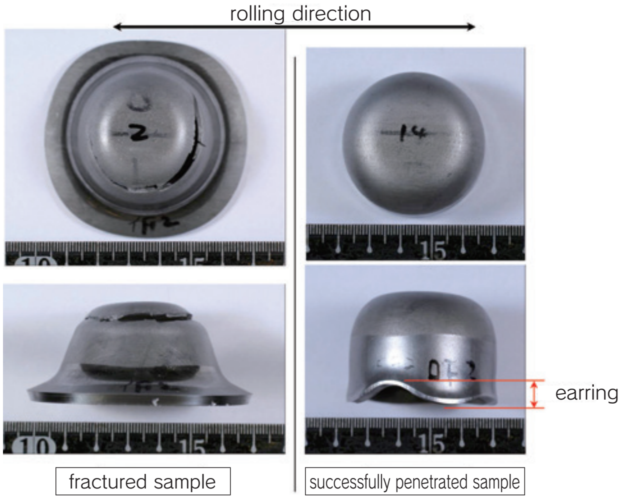


Photo4 Test pieces after deep drawing test (typically deformed samples)

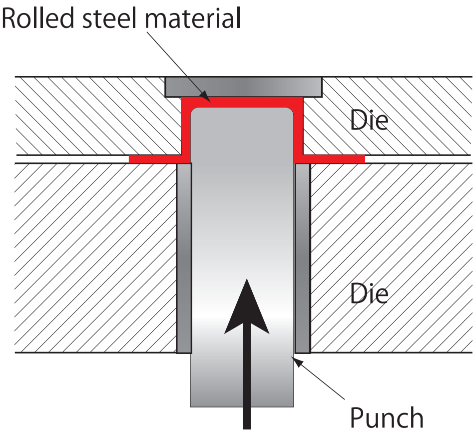


Fig.8 Schematic illustration of deep drowing test tool shape

Table8 Results of deep drawing test

blank diameter (mm)	○: good, ×: bad	LDR
φ78	○	2.20
φ80	○	
φ82	○	
φ84	○	
φ86	○	
φ88	○	
φ90	×	
φ92	×	

3.3. Press formability (FLD)

While the previous section showed the results of various formability tests, they alone cannot predict the press formability for real complicated shapes. Therefore, we drew “Forming Limit Diagram (FLD)” to estimate the forming limit in the actual press working; the FLD is obtained by giving the various forming paths from the equal biaxial strain state path to uniaxial strain state path through tests such as tensile and fluid pressure bulging tests.

Next, we explain the FLD more in detail. We measure the major($\varepsilon 1$)and minor ($\varepsilon 2$) strains at the necking part by Scribed Circle Method just before fracture occurs. And we plot these values on the coordinate plane of $\varepsilon 1$ and $\varepsilon 2$ and draw a FLD by linking those points. The FLD shows how forming limits change by the ratio of $\varepsilon 1$ to $\varepsilon 2$. Generally speaking, the forming limit becomes smaller near the plane strain condition where $\varepsilon 2/\varepsilon 1 = 0$. FLD is used widely for selecting materials and/or solving forming problems. (FLD is expressed as the deformation in x and y directions and the working limit for drawing to bulging as shown in Fig.9.)

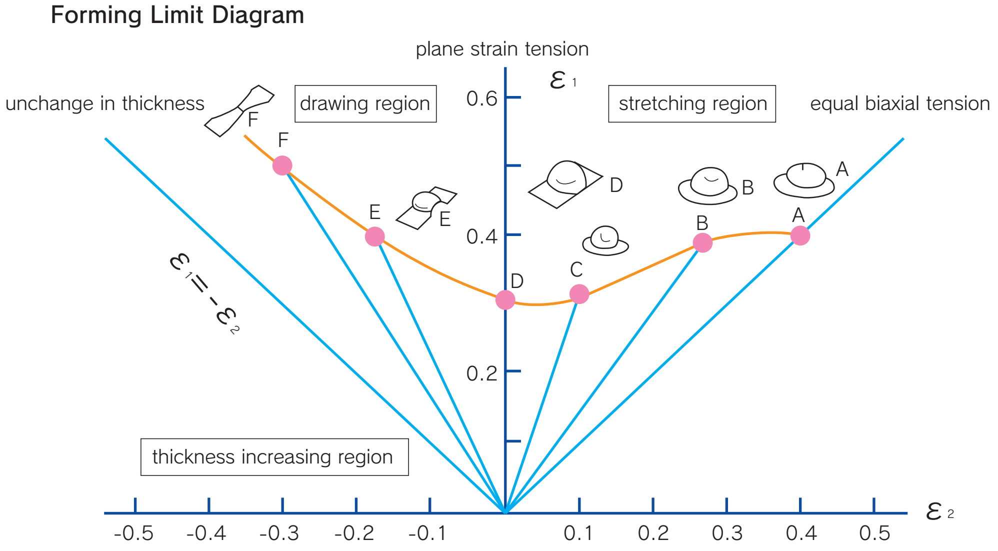


Fig.9 Explanation of FLD

Table 9 and Fig.10 show the test conditions and the FLD obtained, respectively. The maximum strain and the minimum strain change by the deformation mode; as shown in Table 10, the former is in the range from 43% to 72% and the latter is in the range from -18% to 60%.

Table9 FLD test conditions

forming mode	test piece (C×L)	lubricant	work speed	blank holding force
equal biaxial deformation	210×210 mm	hydro-static bulging	30mm/min	100ton
unequal biaxial deformation (1)	200×200 mm	hydro-static bulging		100ton
unequal biaxial deformation (2)	200×200 mm	hydro-static bulging		100ton
plane strain deformation	200×120 mm	no lubricant	10～20mm/min	60ton
uni-axial tensile deformation	200× 35 mm	—		–

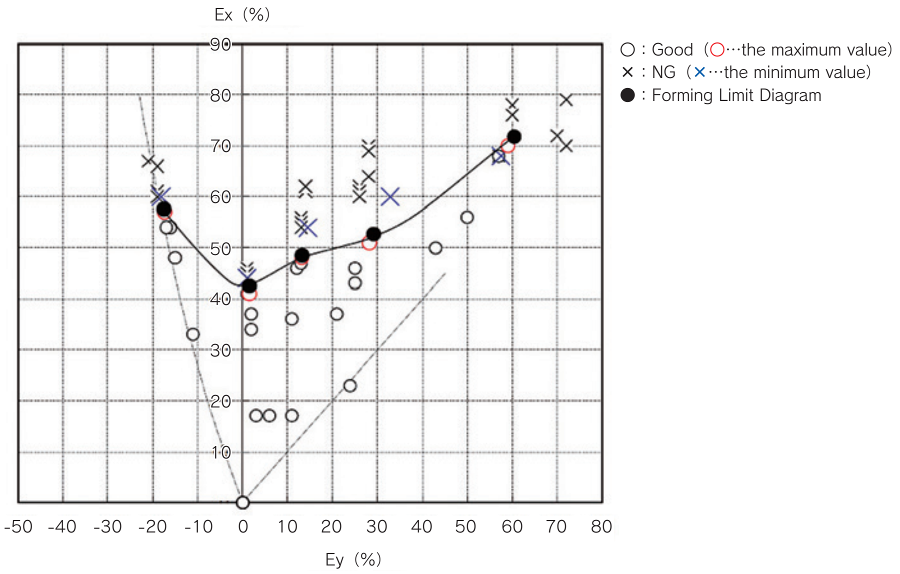


Fig.10 Forming limit diagram

Table10 Results of FLD test

Deformation mode	forming limit	
	Ex(%)	Ey(%)
equal biaxial deformation	72	60
unequal biaxial deformation (1)	53	29
unequal biaxial deformation (2)	48	13
plane strain deformation	43	2
uni-axial tensile deformation	58	-18

3.4. Fatigue property

We carried out tensile fatigue test and plane bending fatigue test, of which test pieces are shown in Fig.11. Table11 shows the test conditions. Table12 and Fig.12 show the test results. The tensile fatigue limit and plane bending fatigue limit were 320 MPa and 170 MPa, respectively.

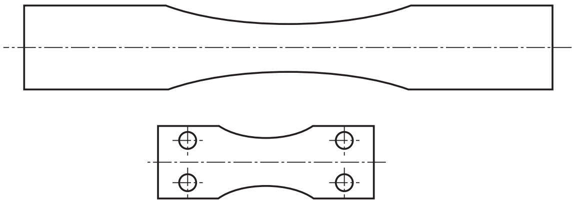


Fig.11 Specimen of fotlgue test

Table11 Fatigue test conditions

item	tensile fatigue test	plane bending fatigue test
stress ratio	0.05	-1.0
test frequency	20Hz	
maximum number of cycles	1×10^7 times	

Table12 Results of fatigue test

No.	tensile fatigue test		note	plane bending fatigue test		note
	maximum stress (MPa)	number of cycles (cycle)		maximum stress (MPa)	number of cycles (cycle)	
1	200	2,015,000	no failure	170	10,000,000	no failure
2	240	4,968,000	no failure	180	3,878,300	failure
3	300	10,000,000	no failure	190	1,394,800	failure
4	320	10,000,000	no failure	200	1,145,800	failure
5	330	3,789,981	failure	220	473,200	failure
6	340	478,486	failure	230	293,600	failure
7	350	281,532	failure	250	166,700	failure
8	370	13,540	failure	270	85,000	failure
9	380	9,329	failure			
10	390	2,931	failure			

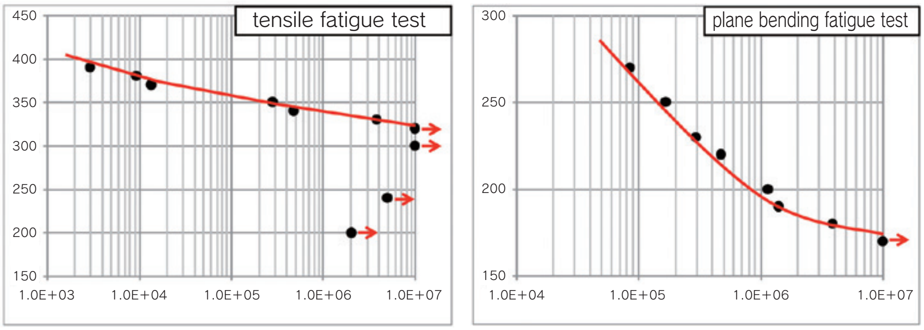
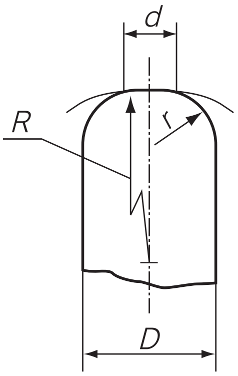


Fig.12 S-N curves

3.5. Spot weldability

3.5.1 Range of suitable welding current

The current range, from the minimum current required to give a nugget diameter of 4√t(5.06 mm in the present test) to the current resulting in the onset of expulsion was adopted as the suitable welding current range. We employed DR-shaped electrode of d=6 mm shown in Fig.13 and carried out spot welding on the basic conditions in Table13. Table14 lists each condition and its measured nugget diameter.
It is concluded from Table14 and Fig.5 that the minimum limit current is 6.3 kA and the suitable current range is 2.5 kA (Table 15). Photo.5 shows typical cross sections of the welds.



mark	D type	DR type		
face diameter D / Model	r	R	d	r
10	5			
13	6.5	32 63	5	6.5
16	8	40 80	6	8
20	10	50 100	8	10
25	12.5			
32	16			
40	20			

reference : JIS C 9304(1999)

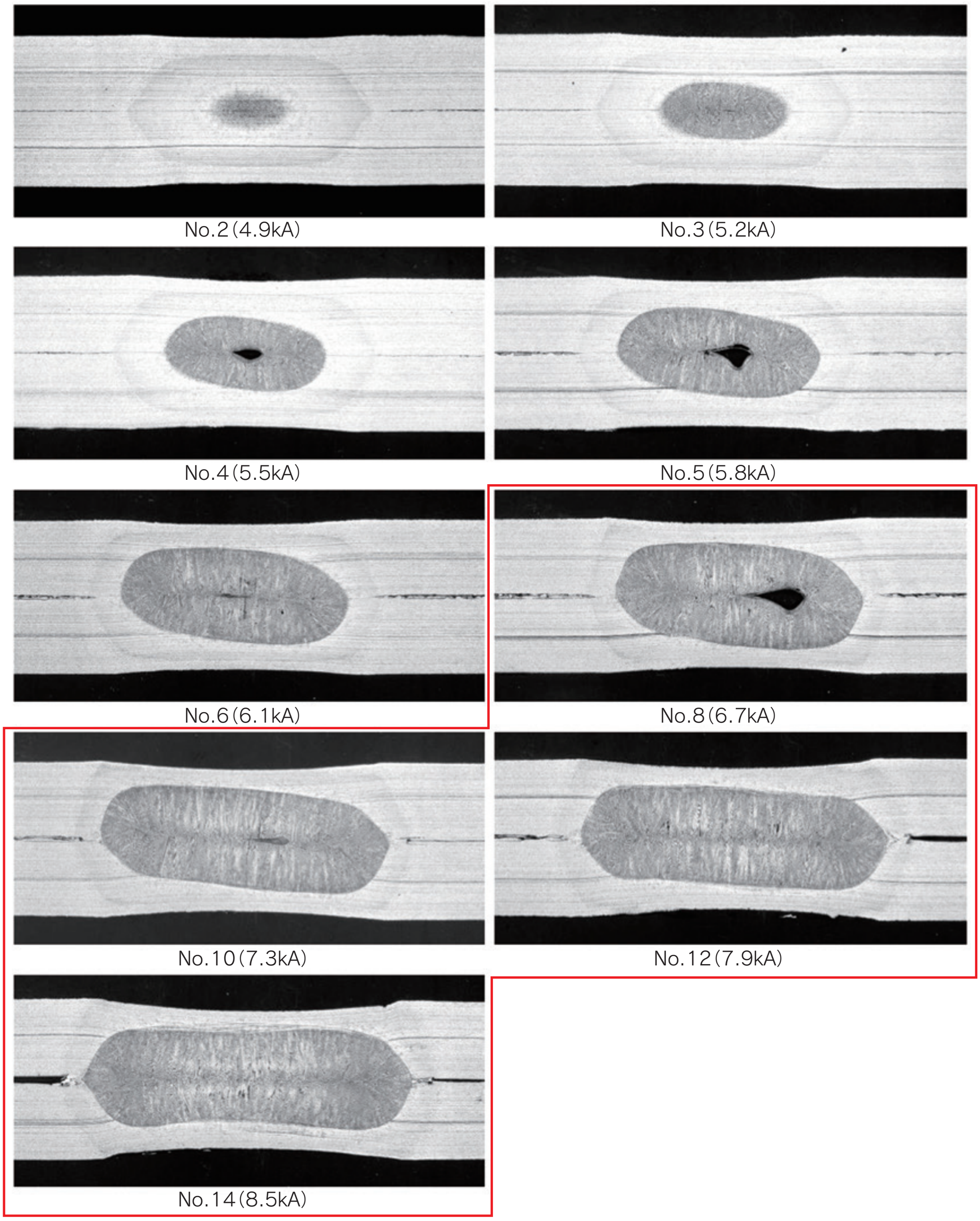
Fig.13 Electrode shape

Table13 Base conditions for spot welding

electrode	1%Cr-Cu dome type ϕ16mm tip (nose) ϕ6mm(R40)
initial pressure time	29cycles/50Hz
electrode force	270kg
welding time	15cycles/50Hz
holding time	1cycles/50Hz
flow rate of cooling water	top and bottom 2.5L/min.

Table14 Conditions for spot welding and diameters of nugget

test piece No.	welding current (kA)	weld thickness (mm)	expulsion	nugget diameter (mm)
1	4.6	3.11	none	–
2	4.9	3.10	none	0.99
3	5.2	3.11	none	2.54
4	5.5	3.11	none	3.35
5	5.8	3.09	none	4.24
6	6.1	3.08	none	4.78
7	6.4	3.07	none	–
8	6.7	3.07	none	5.23
9	7.0	3.04	none	–
10	7.3	3.01	none	6.05
11	7.6	3.00	none	–
12	7.9	3.00	none	6.40
13	8.2	2.94	none	–
14	8.5	2.92	none	6.86
15	8.8	2.82	expulsion	–



No.2 (4.9kA)
No.3 (5.2kA)
No.4 (5.5kA)
No.5 (5.8kA)
No.6 (6.1kA)
No.8 (6.7kA)
No.10 (7.3kA)
No.12 (7.9kA)
No.14 (8.5kA)

Photo5 Cross sections of welds (Enclosure line is appointed at suitable welding current range)

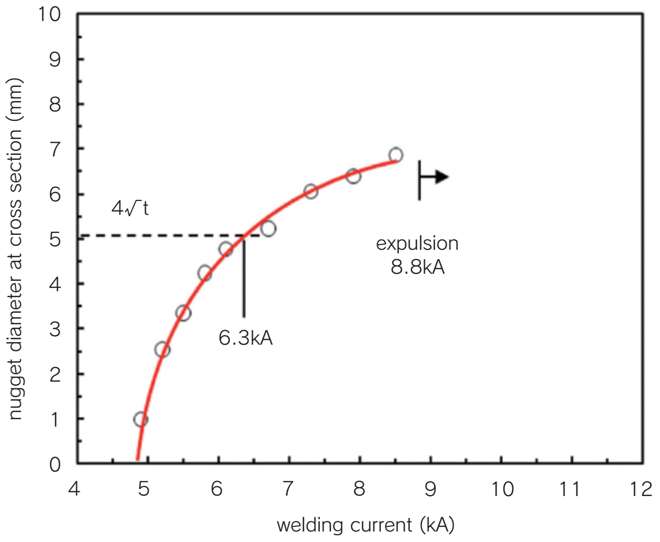


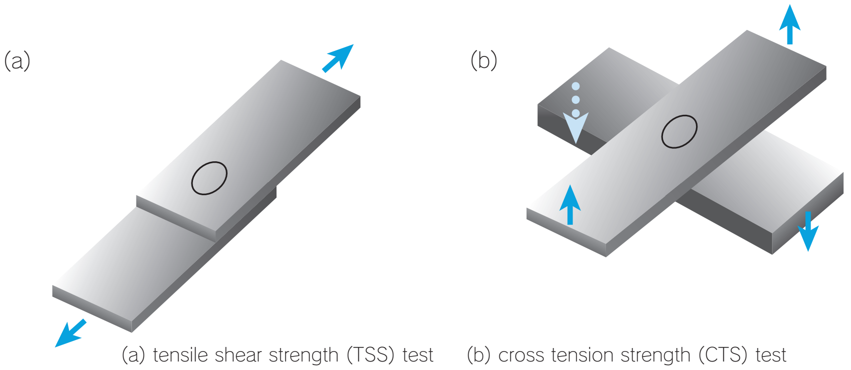
Fig.14 Weld growth curve (nugget diameter against welding current)

Table15 Suitable welding current range

the lowest limit current (4√t)	6.3kA
the upper limit current (expulsion)	8.8kA
Suitable current range	2.5kA

3.5.2 Evaluation of joint strength

We carried out the tensile shear strength (TSS) test and the cross tension strength (CTS) test as shown in Fig.15, where the current 6.3 kA for spot welding was employed by considering the lowest limit current which would deliver nugget diameter (4√t).



(a) tensile shear strength (TSS) test (b) cross tension strength (CTS) test

Fig.15 TSS and CTS tests

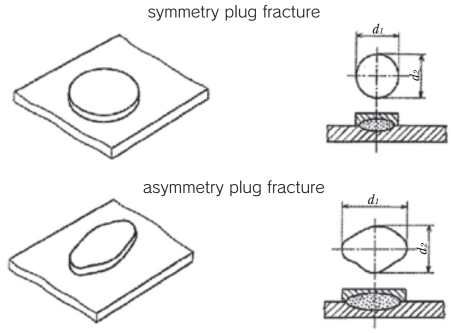
Tables 16 and 17 show the performance of the weld joints and the average joint strengths, respectively. Both of TSS and CTS tests show that the fractured modes are of the mother metal plug. And both of the strengths are higher than those of conventional mild steel sheets, indicating sufficient joint strengths.

Table16　Results of joint performance tests

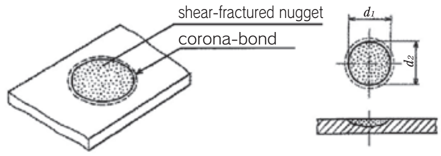
test type	test No.	welding current (kA)	weld thickness (mm)	expulsion	nugget diameter (mm)	fracture mode	joint strength (kN)
TSS (kN)	1	6.3	3.11	none		mother metal plug	11.21
TSS (kN)	2	6.3	3.10	none		mother metal plug	11.09
TSS (kN)	3	6.3	3.11	none		mother metal plug	11.16
TSS (kN)	4	6.3	3.11	none		mother metal plug	11.31
TSS (kN)	5	6.3	3.09	none		mother metal plug	11.21
CTS (kN)	6	6.3	3.08	none		mother metal plug	8.77
CTS (kN)	7	6.3	3.07	none		mother metal plug	8.65
CTS (kN)	8	6.3	3.07	none		mother metal plug	8.60
CTS (kN)	9	6.3	3.04	none		mother metal plug	8.70
CTS (kN)	10	6.3	3.01	none		mother metal plug	8.52
macro	11	6.3	3.00	none	4.36		
macro	12	6.3	3.00	none	4.65		

Table17　Joint strength on average

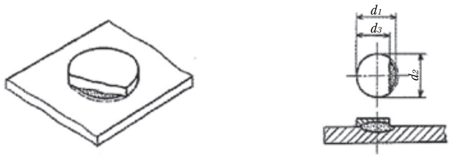
nugget diameter (mm)	tensile shearing test (kN)	cross tension test (kN)
4.65　($3.7\sqrt{t}$)	11.20 (σ=0.072)	8.65 (σ=0.085)



a)　in case of plug fracture



b)　in case of interfacial fracture



c)　in case of partial plug fracture

reference：JIS Z 3136(1999)

Fig.16　Fracture pattern

TOKYO STEEL MANUFACTURING CO.,LTD.

HP http://www.tokyosteel.co.jp

Location

Head office	Kasumigaseki-Tokyu Bldg15F, 3-7-1, Kasumigaseki, Chiyoda-ku, Tokyo 100-0013, Japan Telephone(81)3-3501-3223 FAX.(81)3-3580-8859 (sales)
Osaka branch office	Osaka Kokusai Bldg, 3F, 2-3-13, Azuchi-cho, Chuo-ku, Osaka-shi, Osaka 541-0052, Japan Telephone(81)6-6264-1368 FAX.(81)6-6264-6396
Nagoya branch office	Nittochi Nagoya Bldg, 7F, 2-1-1,Sakae, Naka-ku, Nagoya-shi, Aichi 460-0008, Japan Telephone(81)52-203-0855 FAX.(81)52-203-3021
Kyushu branch office	3-5-1, Minami Futajima, Wakamatsu-ku, Kitakyushu-shi, Fukuoka 808-0109, Japan (Located at Kyushu Plant) Telephone(81)93-791-5988 FAX.(81)93-701-3581
Okayama sales office	4-1-1, Minamise, Kurashiki-shi, Okayama 712-8055, Japan (Located at Okayama Plant) Telephone(81)86-455-7169 FAX.(81)86-455-3105
Utsunomiya sales office	11-1, Kiyohara-kogyo-danchi, Utsunomiya-shi, Tochigi 321-3231, Japan (Located at Utsunomiya Plant) Telephone(81)28-670-6235 FAX.(81)28-670-6238
Tahara Plant	2-1-3, Shirahama, Tahara-shi, Aichi 441-3436, Japan Telephone(81)531-24-0810 FAX.(81)531-24-0818
Okayama Plant	4-1-1, Minamise, Kurashiki-shi, Okayama 712-8055, Japan Telephone(81)86-455-7151 FAX.(81)86-455-3105
Kyushu Plant	3-5-1, Minami Futajima, Wakamatsu-ku, Kitakyushu-shi, Fukuoka 808-0109, Japan Telephone(81)93-791-2635 FAX.(81)93-791-2639
Utsunomiya Plant	11-1, Kiyohara-kogyo-danchi, Utsunomiya-shi, Tochigi 321-3231, Japan Telephone(81)28-670-5607 FAX.(81)28-670-5608
Takamatsu Steel Center	5-1-1, Asahi-machi, Takamatsu-shi, Kagawa 760-0065, Japan Telephone(81)87-822-3111 FAX.(81)87-822-3117

edited 2022 June