Development of resin-coated stainless steel in Japan

by

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1990

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1. Introduction

Japanese production of stainless steel has ranked among the top world producers since 1970. Pioneering efforts to find new markets for stainless steel, have been a cooperative undertaking of manufacturers and distributors. Research and development in production technology has contributed to this progress. One of the successful developments is Resin Coated Stainless Steel (RCSS).

An opportunity developed for the trial application of thin-gauge stainless steel to exterior roofs and side walls of residences and factories where prevailing materials exhibited inadequate durability. Initially, thin gauge 2D-finish SUS 304 —Unified Numbering System (UNS) S 30400 — was used for this purpose together with an expectation of avoiding light reflection.

Initial trials highlighted the need for soft temper to avoid excessive spring back during fabrication associated with the high hardness and strength of tempered materials. Rusting in initial trials caused by severe sea salt adhesion pointed to the need for a coating that would provide the necessary protection. RCSS was the successful result of several years of trial and error.

During the initial production period of RCSS, various specifications were developed by a number of manufacturers. Standardization to Japanese Industrial Standard (JIS) G3320, and *Nonflammable Construction Material No. 1006*, was approved in March 1980 and July 1981, respectively. A *Processing Manual* was prepared in April 1985, in a cooperative undertaking by the Japan Stainless Steel Association (JSSA) and others. A rapid increase in demand for RCSS resulted, as shown in Fig. 1.

Recently RCSS has been further developed to accommodate consumer requests for improved weathering resistance, transparent coating, copper appearance, and weldability.

Stainless steel powder dispersed in the resin coating provides the necessary electrical conductivity to permit welding through the coating and the substrate and result in a waterproof joint. More than 800 000 m^2 (4 000 tons of substrate) of coating were installed in 1989. And further RCSS market growth is expected as a result of the powder/resin development.

Details of typical RCSS products follow.

2. Resin-coated Stainless Steel (Japan Industrial Standard G3320)

2-1 Substrate

Stainless steel sheets of SUS 304 (UNS S 30400) are used mostly with SUS 316 (UNS S 31600), high-purity ferritic stainless steel being in lesser use. The essential characteristics required for building roofs or outside walls are soft temper and good coating adhesion.

Fine grain size of stainless steel has been the usual requirement in stainless steel to prevent the occurrence of orange-peel surfaces during cold working of thin plates used in the manufacture of food machinery and kitchen equipment. Such stainless steel sheets are too difficult for manual handling, however, and undesirable if not unusable as RCSS substrates. Therefore, heat treating, and a little higher temperature for a longer time in the final annealing step, will produce favorable grain size and softness in steel sheets used for RCSS substrates. Fig. 2 shows the relationships between grain size and hardness with regard to longer annealing times and higher

annealing temperature. This may be achieved by adjusting process line parameters.

Good adhesion of resin coating is generally achieved by employing shotblasted skin pass rolls at the final stage to develop the necessary surface roughness. This results in good anchoring adhesion of the resin primer paint to the rough surface of the substrate sheets.

2-2 Resin Paint

To conform with the anti-weathering and anti-corrosion characteristics required by RCSS, silicone polyester and silicone acryl resin for general purpose use, and vinylidene fluoride resin for high anti-weathering use, are coating materials specified in JIS G3320. Epoxy resin paint is generally used as primer. Compared with acryl or polyester resin, mainly used in colored galvanized sheets, these resins show considerably superior characteristics in weathering and corrosion protection. Figs. 3. and 4. show the results of accelerated anti-weathering tests of each resin based on an index of color difference and glaze ratio, respectively. Fig. 5. shows the results under natural exposure.

Since these RCSS resins show excellent anti-weathering properties and since stainless steel is used as the substrate, almost no rusting occurs due to cuts or scratches during processing or peeling of the painted film.

2-3 Resin Coating Process

The same coating line for colored galvanized sheets is used for RCSS. Fig. 6 shows the process diagram for colored galvanized sheets. The pre-treatment apparatus in the figure is not used or necessary for RCSS coating because contaminating grease on the stainless steel substrate has been completely removed after forming the special temper skin on the sheet's surface. The chemical treatment step usually involved in the coating process for colored galvanized sheets is not involved in the RCSS coating process.

The outer side of the substrate sheet is coated with epoxy resin during passage through No. 1 coater and the rear side of the sheet is coated by melamine or polyester resin in order to avoid friction during reeling. Thickness of epoxy resin film (after baking) is 5-7 microns to ensure adhesion of the top resin coated thereon. On the rear side, resin film of 8-10 microns in thickness is applied. Through No. 2 coater, the top coating of anti-weathering resin is applied to the outer side of the sheet from 13-17 microns in thickness.

To guarantee the coating for both sides, epoxy resin is applied on each side of the sheets at No. 1 coater, followed by the top coating of anti-weathering resin at No. 2 coater. Either side of the sheet may be treated differently to satisfy exterior or interior use. RCSS is often used for roofs on structures having no side walls, such as warehouses at ports. Fig. 7. shows cross-sections of RCSS for one side guaranteed and both sides guaranteed.

The thickness of stainless steel substrate for RCSS is generally up to 1.0mm compared with 1.2mm for colored galvanized sheets. If, however, thickness is more than 1.0mm in a stainless steel substrate, it must be cut to length and

each length separately but sequentially coated by means of the curtain coating process. Cooling after resin coating is carried out in the appropriate atmosphere for silicone polyester or acrylsilicone resin, while water cooling is necessary after vinylidene fluoride resin coating.

2-4 Properties of RCSS

Table 1 shows mechanical properties of RCSS compared with those of ordinary colored galvanized sheet and copper sheet.

Table 1. Mechanical properties of RCSS of 0.3mm in thickness

Items	RCSS	Color. galv.	Cu
Tensile strength, kgf/mm^2	67.5	34.5	24.2
Yield point 0.2% in proof stress, kgf/mm^2	29.0	28.5	13.6
Elongation, %	57.5	26.7	39.5
Hardness, HV	162	123	90

Figs. 8. and 9. show the bending properties of RCSS compared with uncoated stainless steel. The spring back ratio of RCSS is always lower than that of the uncoated stainless steel shown in Fig. 9. This is attributed to the softening treatment for RCSS and conforms with the handling characteristics required by the field operating manual for exterior applications.

Other chemical and physical properties of RCSS are summarized in Table 2.

Table 2. Other physical and chemical properties of RCSS 0.3mm in thickness

Test items	Test methods	Results
Mechanical		
a) DuPont impact test	500gm steel ball, 12.7mm diameter	No peeling
b) Crosscut Erichsen tape	100 checkers tape. Crossing distance, 1mm; extrusion distance, 5mm	No peeling
c) Bending	180° bending	No peeling
d) Pencil hardness	Mitsubishi pencil	2H - 3H
Saltwater protection		
a) Spraying	5% salt solution, 35°C (JIS 2371)	No corrosion for 2,000 hrs.
b) Immersion	3% salt solution, 50°C	No corrosion for 2,000 hrs.
c) Dry-wet cycle	3% salt solution, 50°C Immersion 25 minutes, plus 5 minutes drying	No corrosion for 370 cycles
Acid protection		
a) Immersion	5% HC1, room temperature	No corrosion for 74 hrs.
b) Immersion	5% acetic acid, room temperature	No corrosion for 150 hrs.
Alkali protection		
a) Immersion	5% HaOH, room temperature	No corrosion for 150 hrs.

Anti-weathering properties of RCSS vary greatly according to the kind of resin used in top coating as shown in Figs. 3 and 5.

Examples of RCSS for roofs are shown in Photos 1 and 2.

3. Weldable RCSS

Since RCSS is essentially a coated stainless steel of improved durability over prevailing materials, construction work involving RCSS is carried out using stainless steel procedures. The jointing area of the sheets, in prevailing construction procedures, is mainly double folded. If the roofs are installed with insufficient slope, water leakage will develop in the jointed area between sheets. Weldable RCSS has been developed in order to prevent such leakage in flat roofs or butterfly-type roofs.

Bending different from ordinary RCSS coated by resins of non-electric conductivity, the top coating of weldable RCSS consits of silicone polyester resin impregnated with stainless steel powder. (The stainless steel powder is made by intergranular corrosion of SUS 304 (UNS S 30400), a patented process of Nippon Stainless Steel Co., Ltd.). Silicone polyester resin is mixed with stainless steel powder to about 20% by weight and electric conductivity of coated film is induced by pressing. Fig. 10. shows a cross-sectional view of weldable RCSS.

Since the specific weight of silicone polyester resin paint plus solvent is around 1.8 prior to baking, and that of stainless steel powder is about 7.9, it is difficult to obtain a well mixed material because of the tendency to separate and stratify. In trials made to avoid such separation, an

auxiliary reagent was stirred into the mixture to promote dispersion and homogeneity. In addition, trials were made to improve paint pick-up by the pick-up roll when there is the tendency for the stainless steel powder to settle out to the bottom of the pool even when the paint is well mixed.

Fig. 11. shows an improved agitating and mixing system to feed paint through a gap between rolls, instead of by pick-up rolls. Adequate of the mixture in the paint pool together with keeping the level of paint pool constant, are important. Fluctuations in agitation will produce irregular patterns.

Where the quantity of stainless steel powder in the paint is too low, electric conductivity will decrease and so will weldability. Where the quantity of powder is too high, adhesion of the paint will diminish and may cause peeling during subsequent processing.

Fig. 12. shows electric conductivity and adhesion of the paints as they relate to the quantities of stainless steel powders mixed in the paints. Around 20% to 30% by weight may be adequate for the stainless steel powder content. Besides electric conductivity, weldable RCSS products are characterized by an attractive appearance.

Typical applications of waterproof roofing using weldable RCSS are shown in Fig. 13.

Photo 3 shows types of welding apparatus used for RCSS processing while Photo 4 shows an example of producing waterproof joints with RCSS during field construction.

4. Transparent RCSS*

A main purpose of RCSS is preventing corrosion of stainless steel used for exterior architecture, as well as introducing color into the design, hence the importance of weathering resistance and stability of the resins used. In order to achieve this objective, weathering-resistant pigment is added to epoxy resin primers to compensate for the inferior resistance of epoxy resins to ultraviolet transmission and degradation.

While opaque RCSS has been satisfactory for use on roofs and side walls of domestic housing, factories and warehouses, the natural finish of stainless steel is preferred for stores, displays an pavilions where architectural design features and appearance are of great importance.

Transparent RCSS has been developed for this purpose. It employs improved silicone resin with the so-called silane-coupling reaction in order to obtain good adhesion on the stainless steel substrate through a one-coat one-bake process without primer coating. As the resin coating film is transparent, retention of the original appearance of the stainless steel is achieved by adding controlled amounts of weather-durable pigment.

Table 3 shows characteristics of the transparent RCSS. Photo 5 is an example of transparent RCSS applied to a roof, displaying the natural and prestigious appearance of stainless steel.

* The product was jointly developed by Nippon Stainless Steel Co., Ltd., Nissan Motor Co., Ltd. and Chisso Corporation

Table 3. Characteristics of Transparent RCSS
(Test piece: 0.3 mm in thickness)

Items examined	Test methods	Results
Film thickness	Film thickness meter	4 - 6 microns
Physical properties		
Surface hardness	Mitsubishi pencil UNI: judged by peeling	over 3H class
Impact resistance	DuPont impact test: 1/2"$^{\phi}$ x 500g x 50cm	No peeling
Adhesion	Erichsen checkers: 6mm in extrusion	No peeling
Bending	JIS G3320: 2 sheets of test pieces	No peeling
Chemical properties		
Humidity	90% room humidity at 50°C for 500 hrs	No change
Boiling water	immersion in boiling water, for 4hrs	No change
Cyclic exposure	in: 3% NaCl for 20 min. heated air at 60°C for 20 min. 95% room humidity at 50°C for 20 min.	No change after 144 cycles
Acid/Alkali resistance - HCl	immersion in 5% HCl for 500 hrs	No change
- H_2SO_4	in 10% H_2SO_4 for 500 hrs	No change
- Alkali	in 10% NaOH for 500 hrs	No change
- Acetic acid	in 5% CH_3COOH for 500 hrs	No change
Durability	Sunshine weatherometer, for 2,500 hrs	Retaining for glaze ratio 85%

5. Recent Trends and Future Development of RCSS

RCSS was developed to satisfy the demand for thin-gauge stainless steel for the exterior facade of buildings. A rapid growth in demand has been attained since the JIS standards for RCSS were established in 1980. Weldable RCSS has contributed to accelerating this market growth rate as well as developing a new market for waterproof installations. Further progress has been made with transparent RCSS to accommodate various design requirements of customers and designers. A recent trend in demand is for RCSS with copper-like appearance or patina color, both of which are in common use.

The demand for RCSS is expected to grow rapidly, in quantity and the number of diversified products. What may become an important ingredient in the future development of the RCSS market is the Japanese national sentiment for beauty.

Considerable growth of RCSS, compared with that of colored galvanized steel sheets, likely can be achieved . . . if co-operation among customers, designers, manufacturers and distributors is properly nurtured.

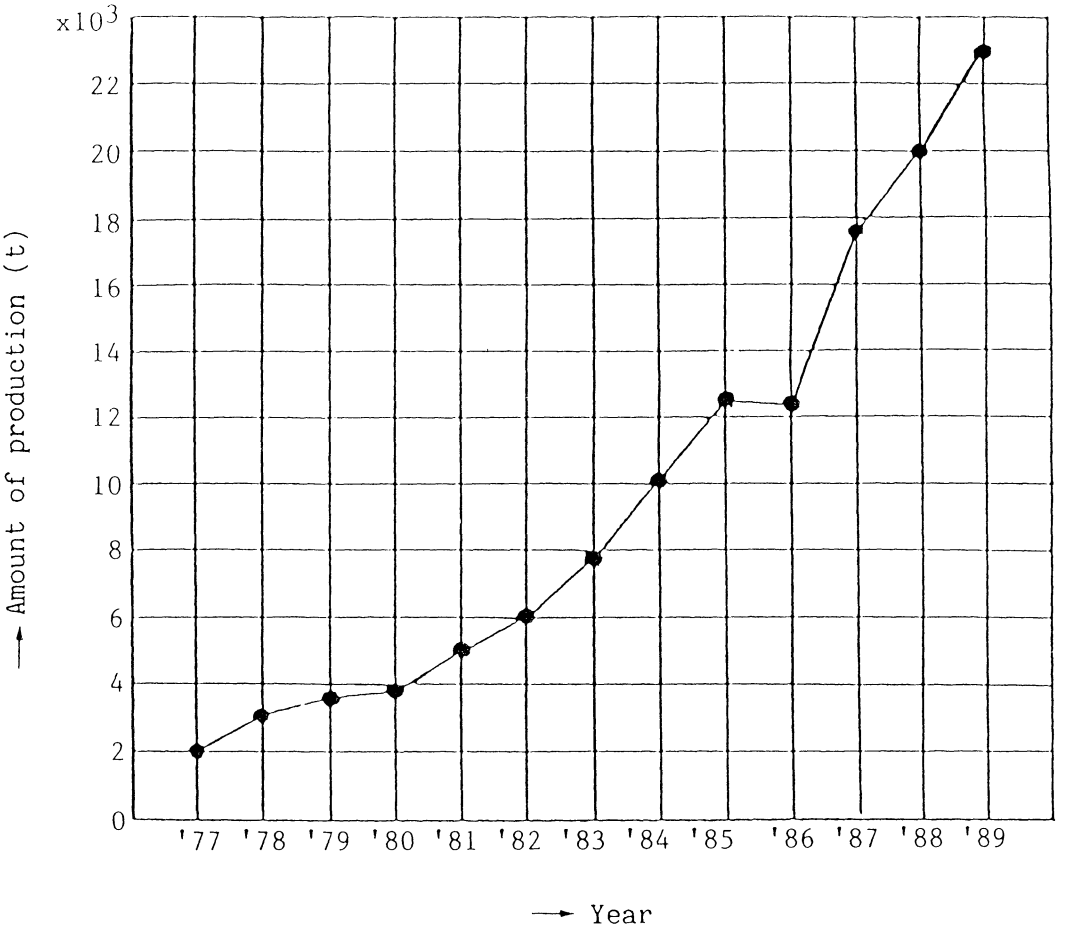


Fig. 1. Production of Resin-coated Stainless Steel In Japan (by JSSA)

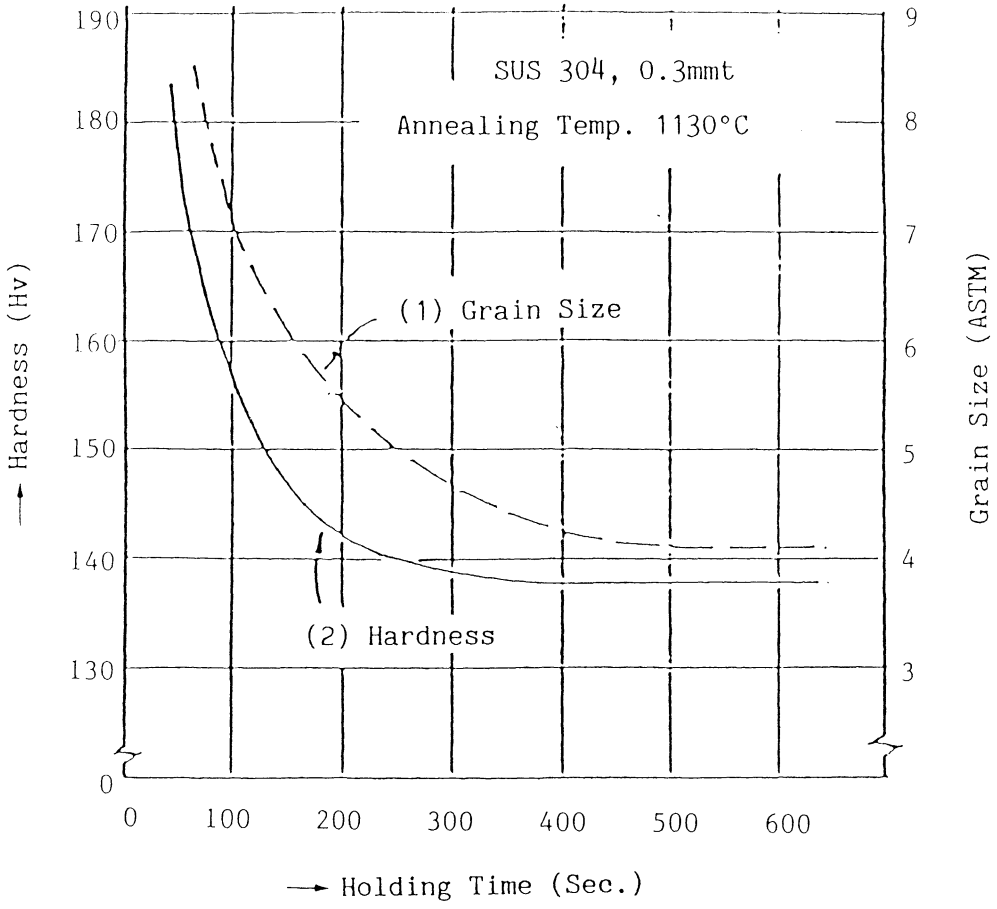


Fig. 2. Relationship between Hardness and Grain Size for Annealed SUS 304 (UNS S 30400) Thin Plate. (Laboratory, Nippon Stainless Steel Co., Ltd.)

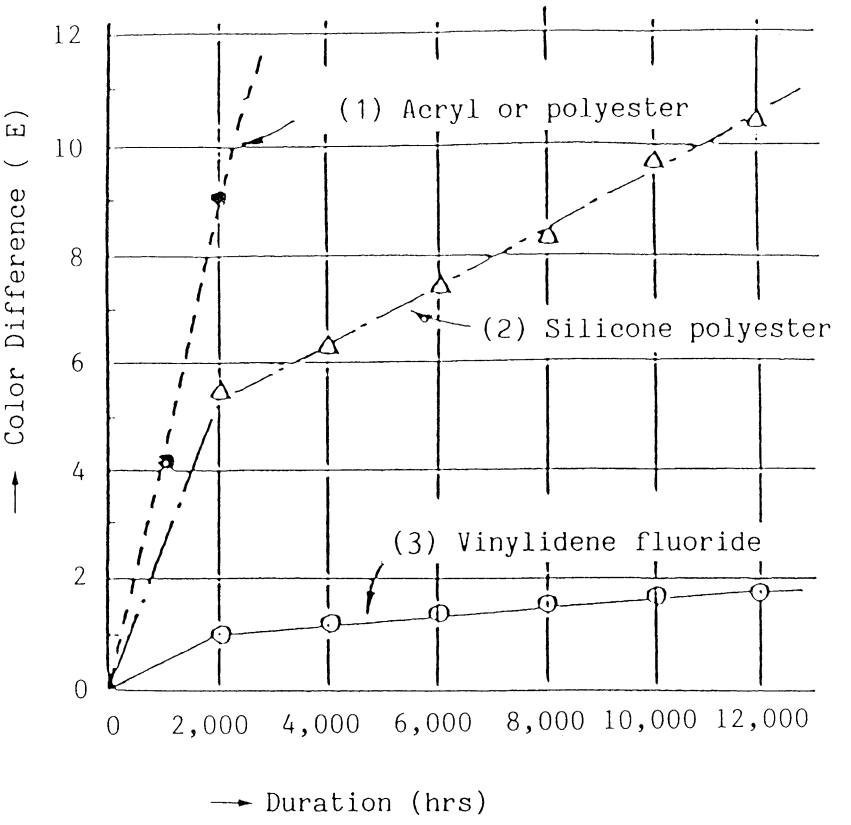


Fig. 3. Results of Accelerated Anti-Weathering Test of Resin used in RCSS: Changes of Color Difference

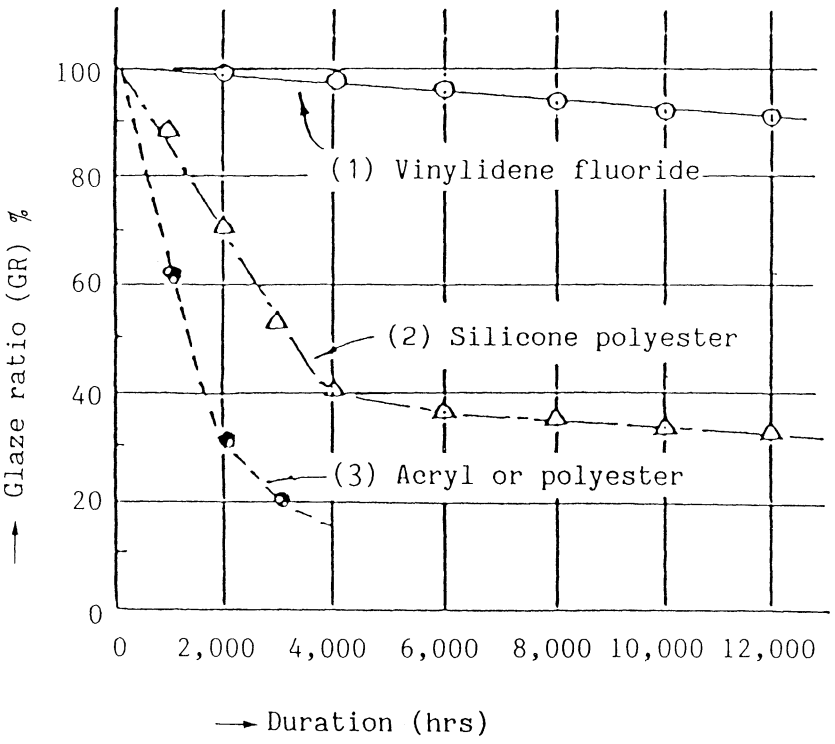


Fig. 4. Results of Accelerated Anti-Weathering Test of Resins used in RCSS: Changes of Glaze Ratio

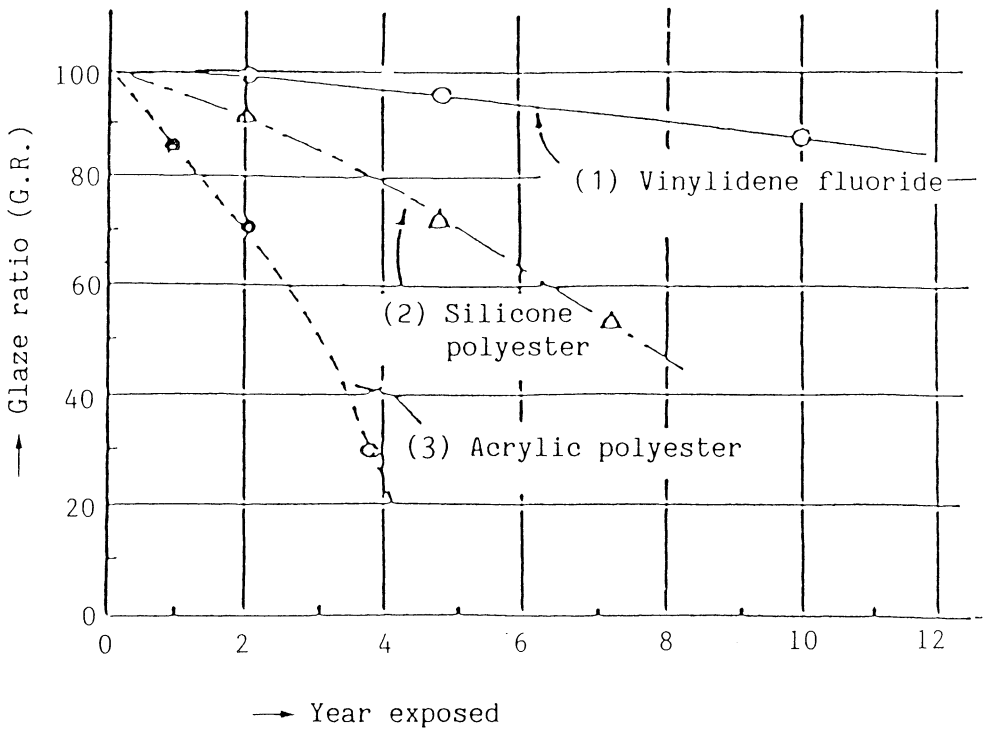


Fig. 5. Results of Anti-Weathering Test of Resins used in RCSS (naturally exposed at Togane): Changes of Glaze Ratio

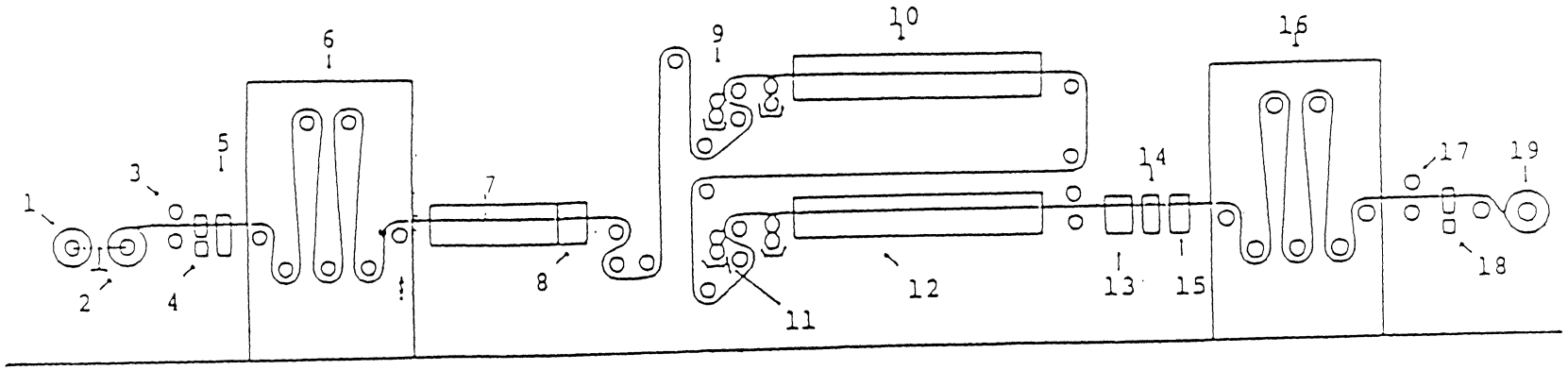
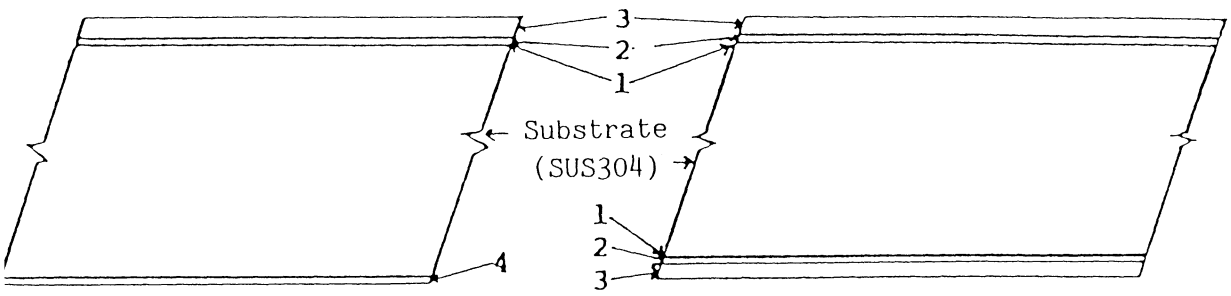


Fig. 6. A Coating Process Diagram for RCSS

1. No.1 Rewinder
2. No.2 Rewinder
3, 17. Leveller
4, 18. Cutter
5. Welder
6. Inlet accumulator
7. Pre-treatment apparatus
8, 15. Dryer
9. No.1 Coater
10. No.1 Oven
11. No.2 Coater
12. No.2 Oven
13. Air cooler
14. Water cooler
15. Dryer
16. Outlet accumlator
19. Reel

a) One side guaranteed

b) Both side guaranteed



1) Temper skin
2) Epoxy resin (ca 7 microns)
3) Silicon polyester or silicone acryl resin (ca 15 microns)
4) Melamine or polyester resin (ca 10 microns)

Fig. 7. Resin/Substrate Cross-sections of RCSS

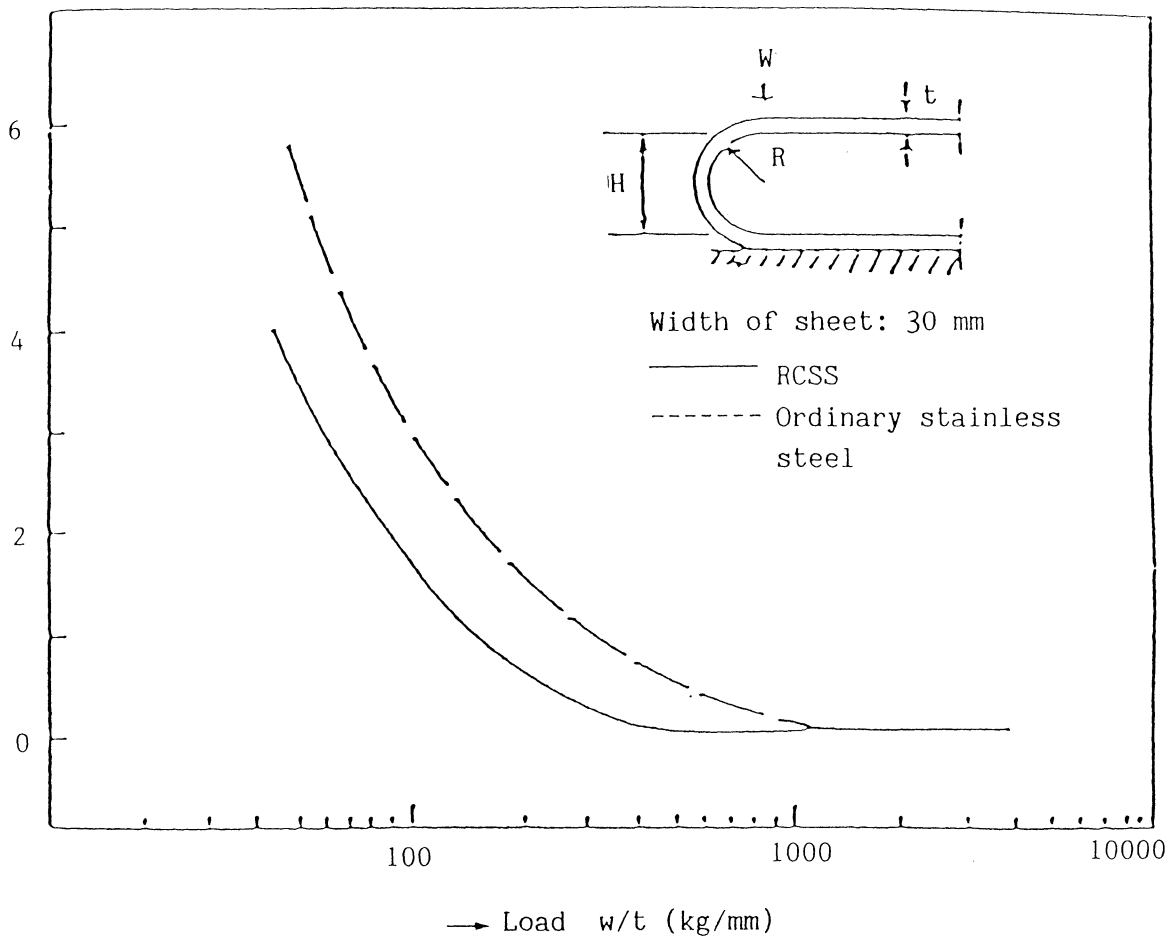


Fig. 8. Relationship of Height and Bending Load for 180° Loading

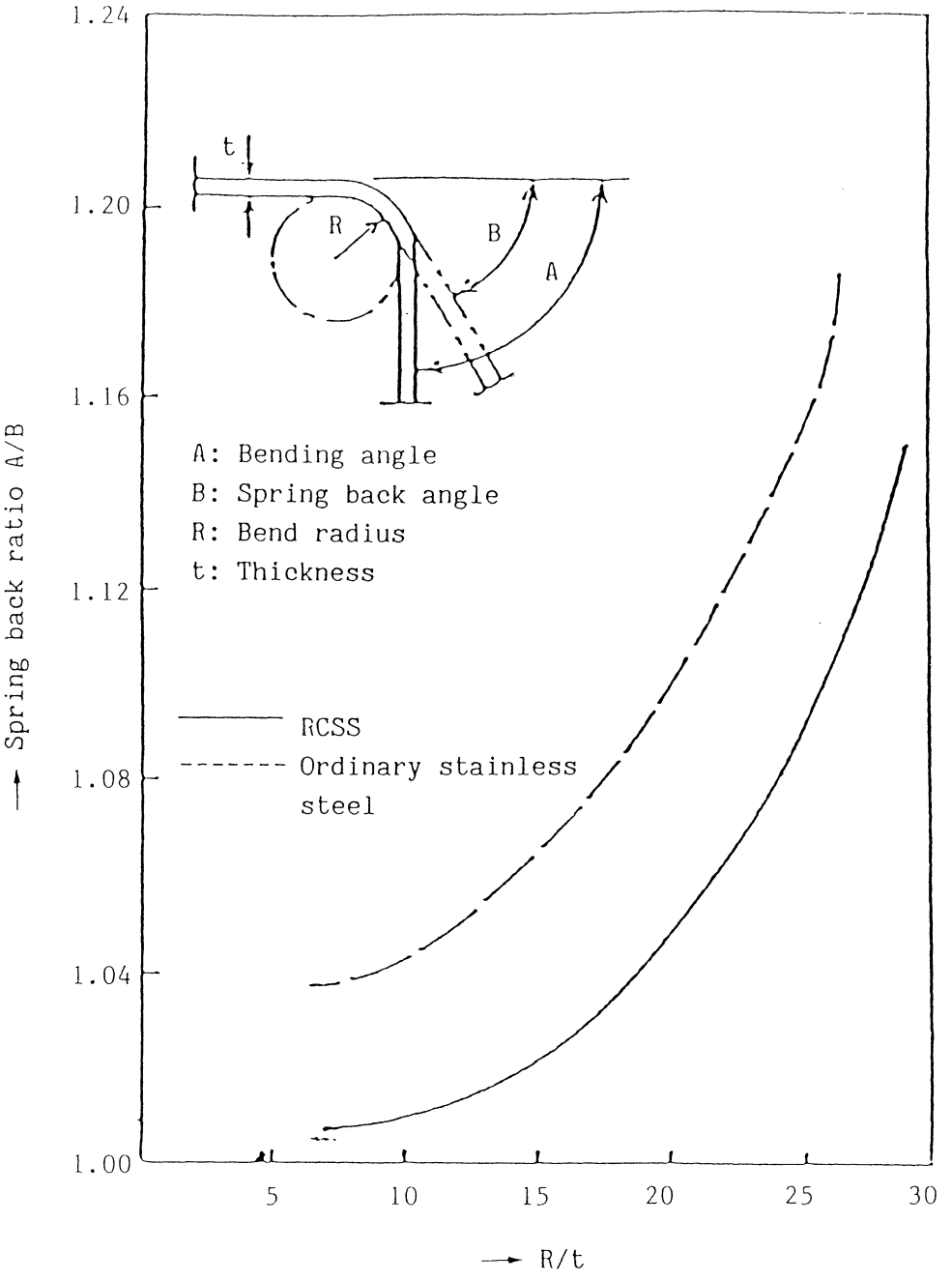


Fig. 9. Comparison of Spring Back Ratio
(Substrate: SUS 304)

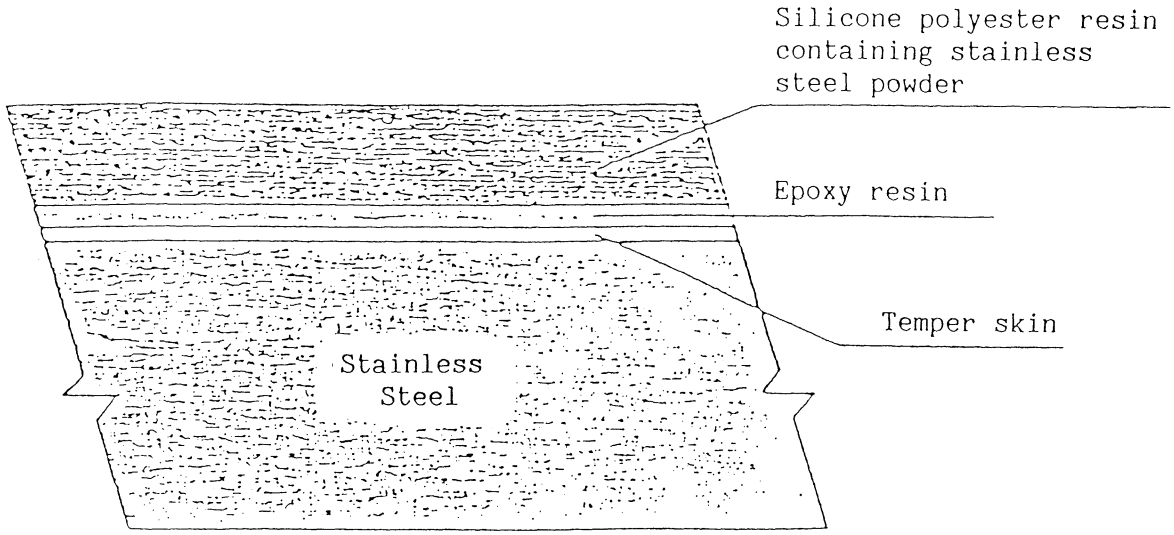


Fig. 10. Cross-section of Weldable RCSS

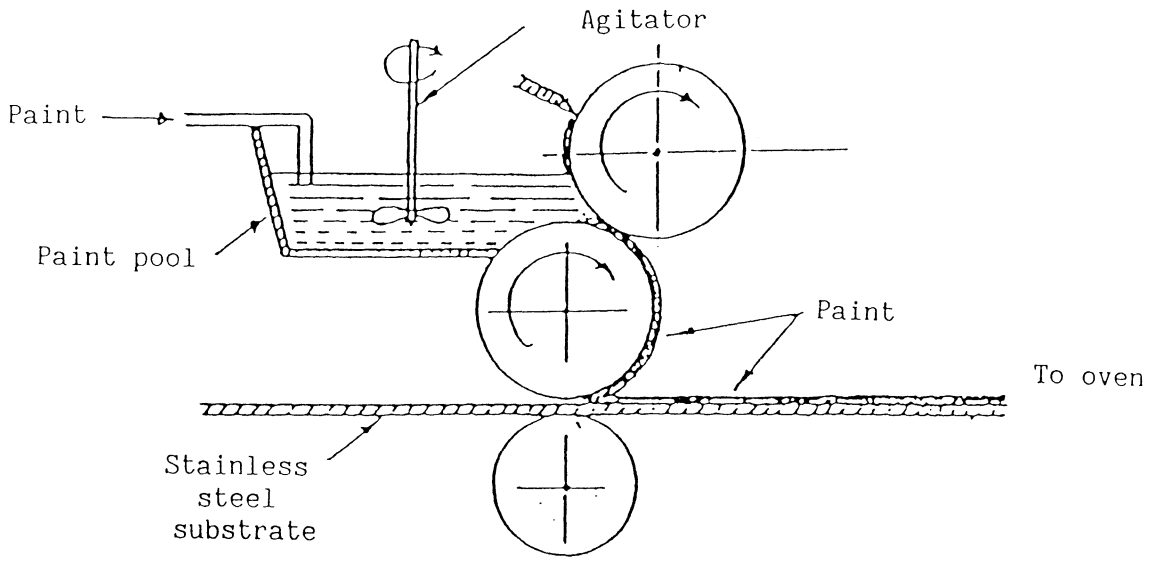


Fig. 11. Improved Painting Line Coating System for Weldable RCSS

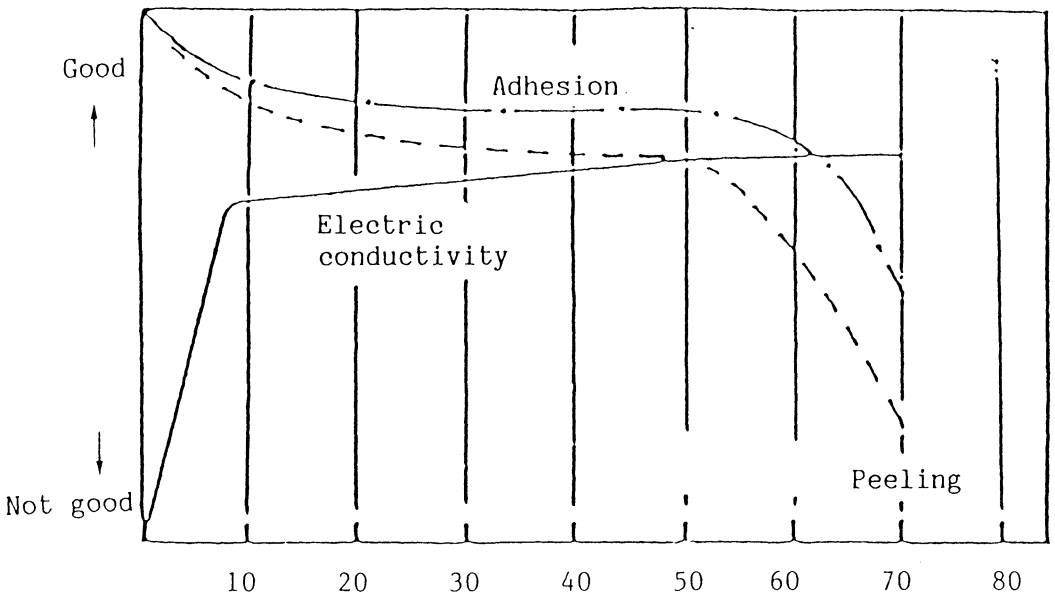


Fig. 12. Adhesion and Electric Conductivity of RCSS versus Stainless Steel Powder Content

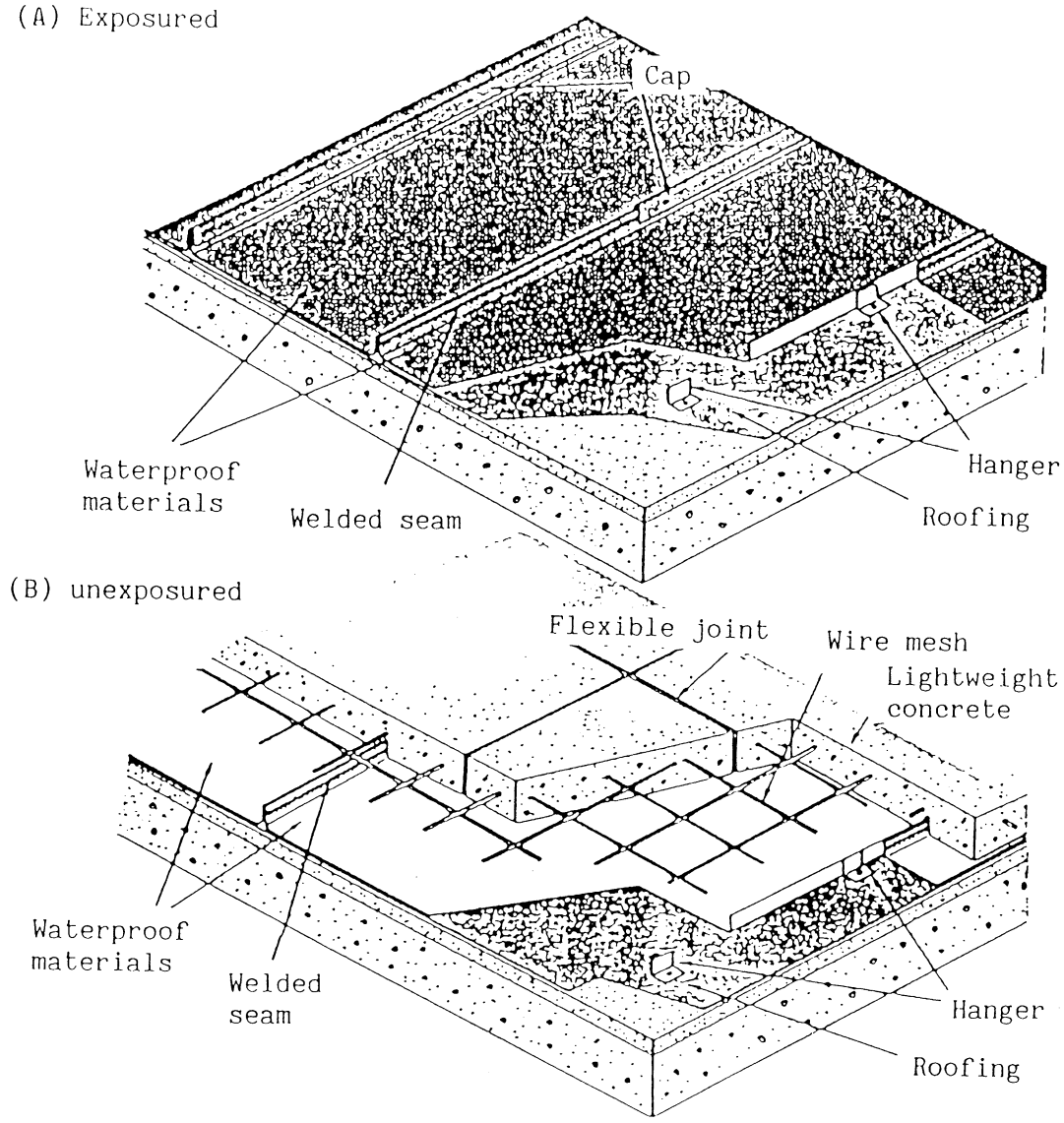


Fig. 13. Typical Cross-sections of Waterproof Weldable RCSS

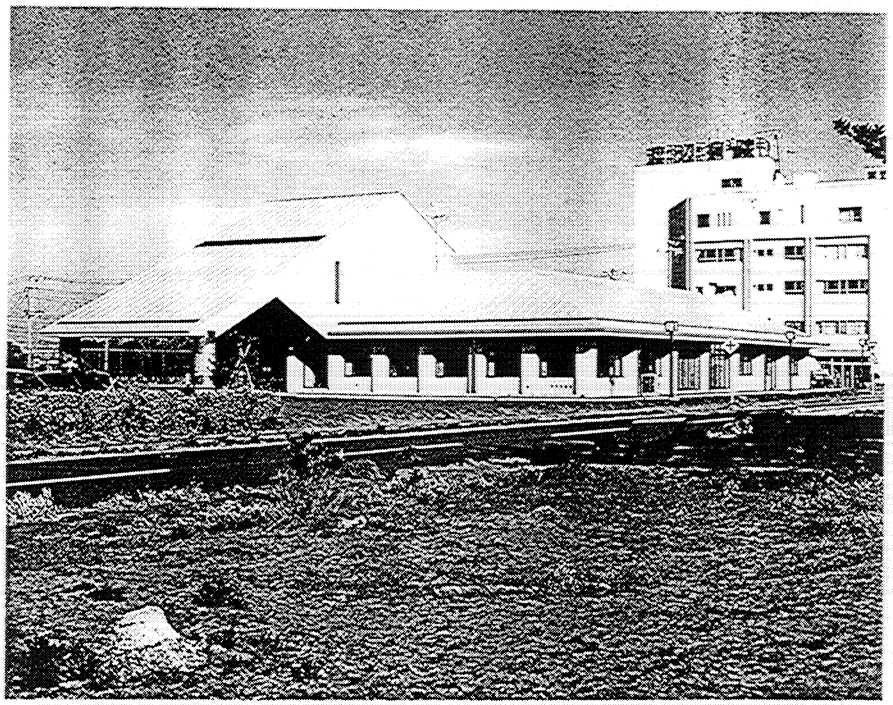
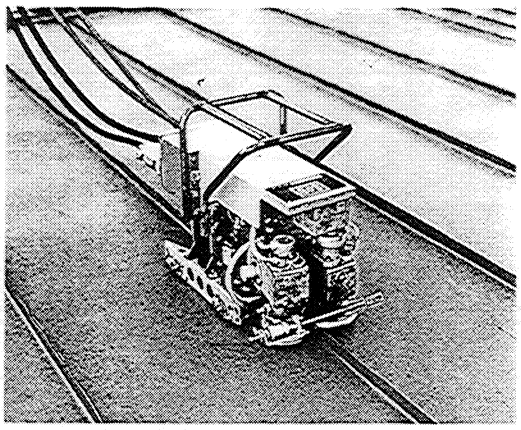
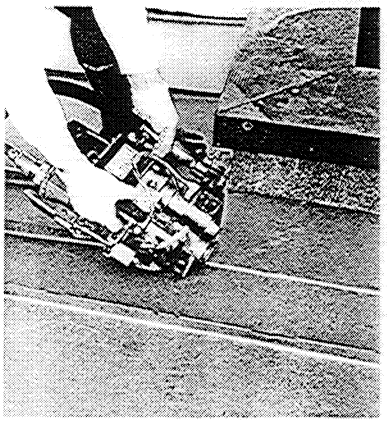


Photo 1. Silicone Polyester Resin-coated Stainless Steel Roof (Dutch-lap Roofing Method) Welfare Homes in Hasaki, Ibaragi Prefecture

Photo 2. Vinylidene Fluoride Resin-coated Stainless Steel Roof (boltless roof) Osaka Prefectural Gymnasium





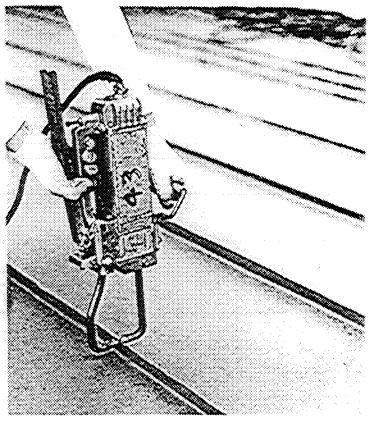


Photo 3. Welding Machine for Waterproof RCSS
including Welder and Spot Welder
1. General seam welder
2. Partial seam welder
3. Spot welder

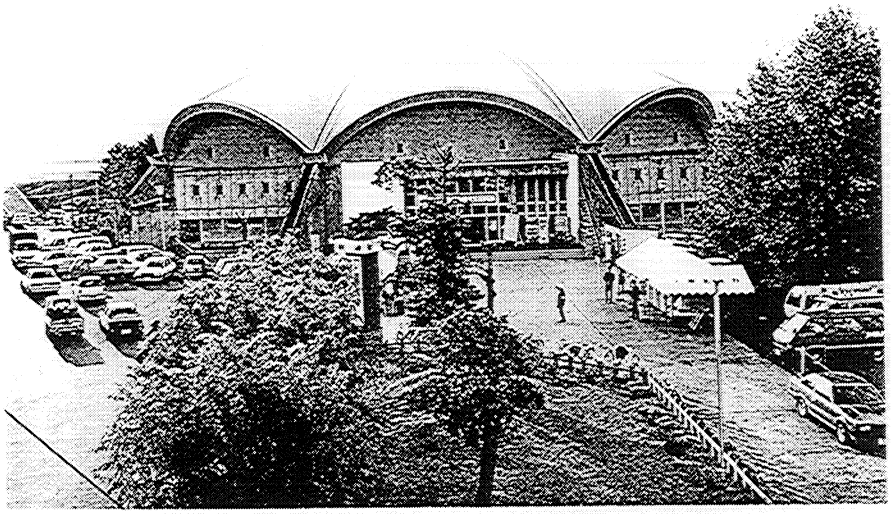


Photo 4. Waterproof Welded RCSS Roof
Sakata City Gymnasium

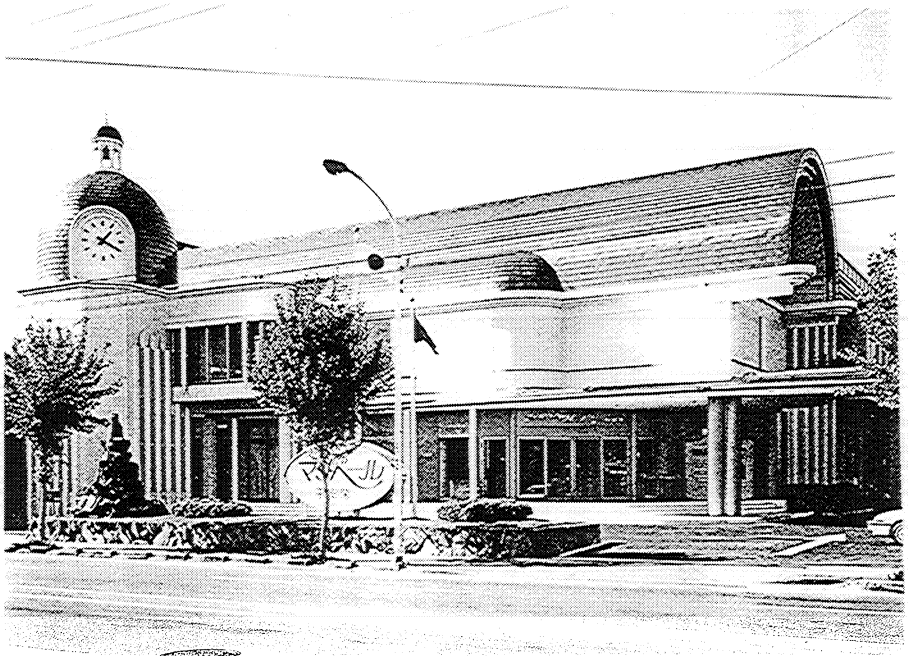


Photo 5. Transparent RCSS Roof (Dutch-lap Roofing Method)
Wedding Hall in Shizuoka City