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Prepainted Steel Sheets Usable without Painting

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Abstract

Here is given an overview of technologies that have contributed to increased applications and uses of prepainted steel sheets while offsetting the disadvantages of prepainted steel sheets. Included are painting technologies that combines formability with hardness and stain resistance by controlling paint film structure, base steel and painting technology that ensure edge corrosion resistance, and mechanical and adhesive bonding technologies that take place of welding. Prepainted steel sheet products recently developed are also described, including prepainted steel sheet with "orange peel" surface that masks paint film defects, antibacterial prepainted steel sheet, and deep-drawable prepainted steel sheet.

1. Introduction

A prepainted steel sheet is a kind of steel sheet product with a finish-coat applied at the steelworks before shipment. This product allows users such as home electric appliance manufacturers to omit coating processes. **Fig.1** shows the typical cross-sectional composition and the specifications of prepainted steel sheets: the obverse side consists of two layers of coating, a primary coat and a finish or top coat, and the reverse side surface usually has a single coating called a protective or service coat. The substrate is generally a hot dip or electro-galvanized sheet.

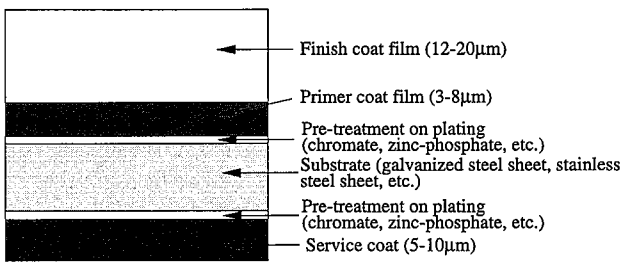

Fig.1 Typical composition and specification of prepainted sheets

2. Expansion of Prepainted Sheet Application

Shipment of the prepainted sheets for home electric appliance manufacturers in Japan saw a significant increase during the 1980's and the production of the product for this industrial sector in 1994 was 300,000 tons, nearly three times that of 1981[1]. Some expect that nearly 100% of the home electric appliances will be manufactured using the prepainted sheets by 2004 with a few exceptions such as automatic vending machines[2].

Such a remarkable growth in the demands for these products can be linked to the facts that prepainted sheets were continuously improved to meet the requirements of the electric appliance industry and that the users have attained the know-how to effectively use the product. Electric appliance manufacturers cite the following factors as the main reasons why they have expanded the use of the prepainted sheets. They are: the improvement in working environment and reduction of waste emissions through elimination of painting, welding and oiling processes, reduction of production lead time, reject ratio in the painting process and process inventory[3-6]. It is also true that the use of the prepainted sheets became rapidly popular as an economical measure to meet environmental regulations in manufacturing plants in the locations where the regulations are more stringent than other areas — typically in the coastal areas of Lake Biwa near

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Table 1 Performances of some of Nippon Steel's prepainted sheets (Trade name "VIEWKOTE")

Evaluation item	Evaluation method / Paint type / Resin		General type						
			I Type	II Type	III Type	IV-1 Type	IV-2 Type	V Type	VII Type
			High workability type	Balanced type in workability and surface physical properties	Stain-resistant type	High workability, stain-resistant type (Universal type)		High corrosion resistance type	High corrosion- and weather-resistance type
			High-molecular polyester	High-molecular polyester	High-molecular polyester	High-molecular polyester		Polyester	Fluoro-carbon type
Surface hardness	Pencil hardness test (scratch hardness)		F - H	HB - H	H	F - H	F - H	H - 2H	HB - H
Workability	Extent of paint crack after 180° bend as per JIS G 3312	20°C (EG/GI)	0T/2T	3-4T/6-7T	5-6T/ -	0T/2T	0-1T/2T	>8t/ -	0T/2T
		0°C (EG/GI)	4T/6-7T	8T/ -	>8t/ -	2T/4T	3T/5T	-	2T/4T
Corrosion resistance	Blister after 240 h of SST as per JIS Z 2371 Width in mm in X-cut portion	(EG/GI)	1-3/0-2	1-3/0-2	1-2/-	1-3/0-2	1-3/0-2	2-3/1-2	1-2/0-1
Stain resistance	Remaining marking ink wiped off with ethanol	Red	×	△	○	○	△	△ - ×	○
		Blue	○	○	◎	◎	◎ - ○	○	◎
		Black	△ - ×	○ - △	◎ - ○	◎ - ○	△	△	○
Weather-ability	Sunshine weather-o-meter 500 h	Color change (ΔE)	1.5	1.3	1.9	0.4	0.5	1.5	0.3
		Gloss retaining rate (GR)	63	65	78	74	94	80	99
Chemical resistance	5% NaOH × 24 h immersion	Gloss retaining rate (GR)	85	95	100	88	96	98	99
	5% H_2SO_4 × 24 h immersion	Gloss retaining rate (GR)	92	99	100	94	99	93	100
Paint coating adhesion	Tape test of cross cut portion as per JIS G 3312	100/100: no peeling	100/100	100/100	100/100	100/100	100/100	100/100	100/100
Application examples			Reflector boar of lighting apparatuses, VTR cabinet, etc.	Washing machine panels, oil room heater base, indoor units of a.c., etc.	Doors and panels of refrig., etc.	Outer panels and internal parts for outdoor units of air conditioners, washing machine panels, etc		Swing panel of trucks, back panels of refrig., etc.	Outer panels for outdoor units of a. c., etc

◎ excellent, ○ good, △ fair, × poor

Function type			
VI Type	A Type	B Type	C Type
Heat resistant, non-sticking type	High adhesive bonding type	Adhesive-application omission type	Ultra-deep-drawability type
PES+PTFE	High-molecular polyester	Special high-molecular rubber type	High-molecular polyester
2H (Rapture)	F - H	HB	F - H
(ALSHEET)4T	0T/2T	3T/4T	2T/ -
-	2T/4T	-	-
(ALSHEET)2-3	1-3/0-2	-	1-3/0-2
◎	○	-	△ - ×
◎	◎	-	◎ - ○
◎	◎ - ○	-	△
-	1.0	-	-
-	68	-	-
-	76	-	85
-	95	-	98
100/100	100/100	100/100	100/100
Inner panels of microwave ovens and oven toasters, top panel of gas heaters, etc	Shelves of refrigeration showcases, etc.	Automobile weather strip cores, metal gaskets, etc.	Automotive oil filter cases, air filters, gas tanks, etc

Kyoto and the lower reaches of the water towards Osaka.

3. Revision of Shortcomings of the Prepainted Sheets

Over the last 10 years, developments in the prepainted sheets has been mainly that of correcting the shortcomings of the product. The principal shortcomings were:

(1) Workability, hardness and stain resistance of the top coat were incompatible with each other.
(2) Inferior corrosion resistance at the edges.
(3) Welding was not applicable and other joining methods had to be employed.

But, as will be described hereafter, these shortcomings have already been solved.

3.1 Compatibility of workability, hardness and stain resistance

Various researches had been done, although mostly unsuccessfully, attempting to find some compromise among workability, hardness and stain resistance of the coating film through improvements in resin composition and paint mixture until a technology was developed whereby hardness and stain resistance could be improved, while maintaining good workability by selectively condensing melamine-formaldehyde resin near the surface of the top coat layer[7] and thus a coating layer having an excellent performance hitherto unattainable was made available. This technology, commercially applied to Nippon Steel's VIEWKOTE-IV[8,9], made it possible for workability, hardness and stain resistance to coexist at high levels in combination with improvements in resin composition and paint mixture. Some aspects of the performance of VIEWKOTE-IV are shown in **Table 1** compared with other conventional prepainted products[10].

3.2 Corrosion resistance of edges

It has been made clear through a 5 year exposure test conducted at a coastal location in Okinawa that a sufficient corrosion resistance at edges can be secured by selecting hot dip galvanized sheets with an adequate coating mass as the substrate[11]. **Fig.2** shows the relationship between the plating type and the width of the coating blister and red rust from edges after an exposure test. It is clear from the figure that for preventing red rust from forming on the edges, hot dip galvanized sheets and Zn-Al alloy plated sheets are suitable as a substrate.

Fig.3 shows the relationship between zinc layer-thickness ratio (coating mass in g/m² divided by steel sheet thickness in mm) and the width of coating blister and red rust from edges after an exposure test. If the zinc layer-thickness ratio is 70 - 75, red rust formation

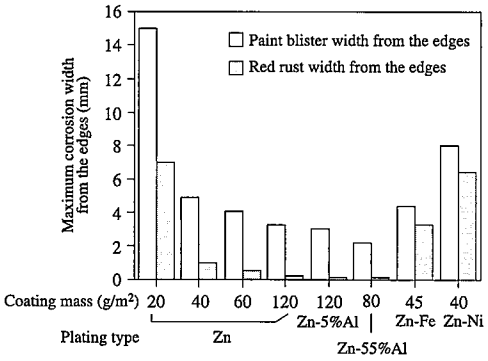

Fig.2 Relationship between plating type and coating mass and edge corrosion – after a 5-year exposure test in Okinawa –

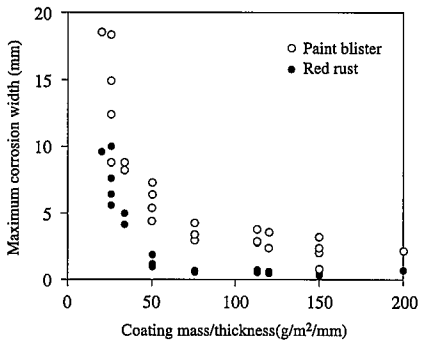

Fig.3 Effects of zinc layer-thickness ratio (coating mass / steel sheet thickness) on edge corrosion resistance after 5-year exposure test in Okinawa (plating mass 20 - 138 g/m², steel thickness 0.5 - 1.0 mm)

from the edges after an exposure for 5 years at seaside in Okinawa would not be conspicuous[11]. Based on this result, a prepainted sheet product capable of withstanding outdoor use for a long period was developed using a hot dip galvanized sheet having sufficient corrosion resistance as the substrate and involving further improvements in the coating system[11].

Fig.4 shows a comparison of corrosion resistance of this prepainted sheet (Precoat B in the figure, coating mass 60 g/m², steel thickness 0.7 mm, zinc layer-thickness ratio 86) fabricated into the outside unit of an air conditioner as shown in **Fig.5**. It was exposed at seaside of Miyakojima Island for 3 years with that of a post-painted sheet (using a galvannealed sheet as the substrate, coating mass and steel thickness same as above) actually used in an exposure condi-

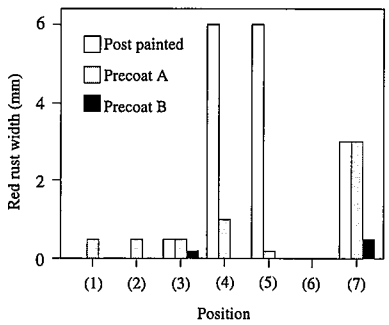

Fig.4 Red rust width of an outdoor unit of air conditioner after a 5-year exposure in Okinawa

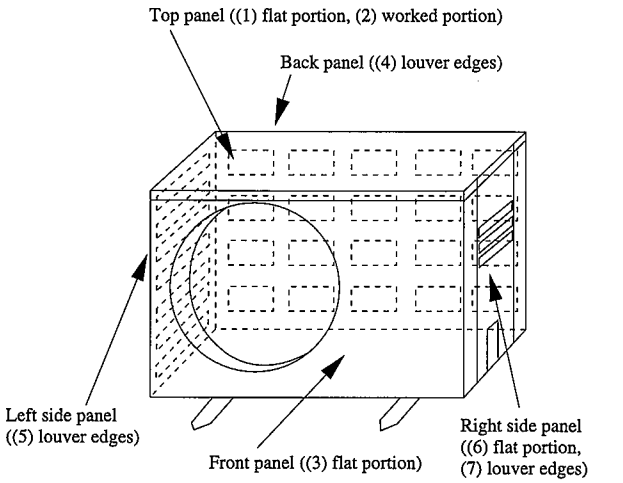

Fig.5 Exposure-tested outdoor unit of air conditioner and positions of corrosion inspection

tion[12]. The developed prepainted sheet showed less red rust formation than the post-painted sheet at every portion inspected, either in the flat portion or the edges. The prepainted sheets for the air conditioner outdoor units have been commercially used for more than 10 years without any corrosion problems.

3.3 Mechanical joining and adhesion joining

Mechanical joining and adhesion joining are being studied as a substitute for welding. **Fig.6** shows a comparison of joint strength of 2 types of a mechanical joint and an adhesion joint using spot welding. The specimens were prepared as shown in the figure. Tog-L-Loc[13] and thrust-in rivet[14] methods were used as the mechanical joint, and the film type polyester adhesive was used in the adhesion joint. A 0.8 mm thick hot dip galvanized sheet was used as the substrate. Although a mechanical joint is weaker than spot welding in terms of

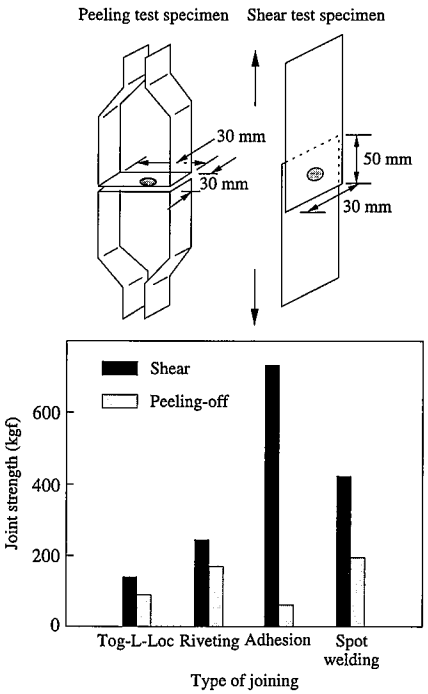

Fig.6 Type of joining and strength (All the sheets are 0.8 mm thick, Spot welding: hot dip galvanized sheet + hot dip galvanized sheet, Others: precoated sheet + precoated sheet)

strength per spot, the difference between shear strength and peeling-off strength of a mechanical joint is small and it is possible to secure enough strength by adequately designing the joint shape and increasing its number. Improvements along this line have been put into actual practice in various applications.

Adhesion joints have a very high shearing strength but they have a low peeling-off strength. This is because the stress concentrates in the small area along the edge at the peeling test, but the problem can be overcome by increasing the stiffness of the metal substrate and by increasing the area of adhesion. Prepainted sheet products having good adhesion joint performance have been developed[10,15].

Fig.7 shows an example of changes of tensile shear strength of an adhesion joint of two prepainted sheets bonded with a 2-component urethane adhesive undergoing a cycle corrosion test (CCT) under a condition shown in **Table 2**[16]. The performances of three mechanical joint methods, Tog-L-Loc, TOX[17] and thrust-in rivet, are shown therein for comparison. As the number of corrosion test cycles increased the shear strength fell but all the fractures occurred not at the joint but in the base metal, leading to a conclusion that the failure was caused rather by deterioration of the base metal. Accordingly, the joint methods discussed above are considered good enough in the service environment where the prepainted sheets can be used.

As described above the characteristics of the prepainted sheets which were once viewed as shortcomings have been largely improved, which fact has directly contributed to the increase of the demands for them.

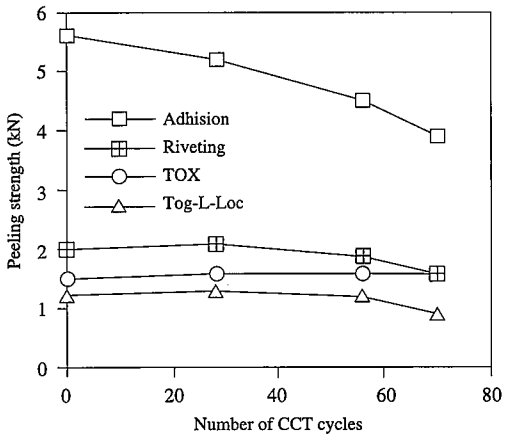

Fig.7 Peeling strength of prepainted sheet joints after cycle corrosion test (sheet thickness 0.65 mm, polyester coating)

Table 2 Cycle corrosion test condition

Sequence	Test item	Condition	Duration
1	Salt spray (SST)	5% NaCl, 35°C	6 h
2	Setting change		1 h
3	Drying	70°C, 60%RH	4 h
4	Setting change		2 h
5	Humidity test	49°C, 95%RH	4 h
6	Setting change		2 h
7	Freezing	−20°C	4 h
8	Setting change		1 h
	1 cycle time		24 h

4. New Prepainted Sheet Products

New prepainted products having novel functions heretofore unavailable were put into market such as heat-resistant non-sticking type sheet which prevents sticking of foods cooked on it[10,18], adhesive-coated type sheet having an adhesive layer so that users can omit the adhesive application process[10,19], etc. Examples of these products having novel functions are also included in Table 1[10]. Various prepainted sheet products having a variety of new functions are being continuously developed yet today to meet requirements of the users. Some of them are described below.

4.1 Orange peel surface finishing

A very even and smooth surface which is unlike the somewhat uneven surface of post-painted sheets has been considered as an advantage of the prepainted products. There are those who use the prepainted products only for a comparatively small portion of their products, however, and in such cases the difference of the surface appearance between the prepainted and post-painted sheets is considered to be a problem. In parallel, it gradually became recognized that small flaws and defects on an uneven surface (like orange peel) are less conspicuous than those on a very smooth surface even when the pencil hardness is the same. Then, a new technique was developed whereby the flow of the finish paint during the hardening process after application is restricted by an additive such that an orange-peel roughness of an order of millimeters is intentionally given to the finished surface. This product having the characteristics shown in **Table 3** is being used for widely varied applications.

4.2 Antibacterial property

Food poisoning cases in summer 1996 in Japan caused by pathogenic colitis germ O-157 triggered wide spread demands for antibacterial property for a variety of industrial products. Now various goods having that required function are highly popular. In response to customer demands, Nippon Steel developed a prepainted sheet product having the antibacterial function against colitis germs for applications to food-related appliances such as refrigerators, freezers, microwave ovens, etc. Technical keys to forming an effective and long-lasting antibacterial film on the sheets are:

(1) Selection of antibacterial agents which do not deactivate at high temperature and the control of reduction of the agents by light.
(2) Use of a new carrier capable of releasing the agents under conditions favorable for germ colony forming.

Fig.8 shows the decrease coefficient of colony forming unit D24 of the developed antibacterial prepainted sheets after exposure to a variety of environmental conditions. For comparison, the performance of a similar product using zeolite as the carrier is shown. The decrease coefficient of colony forming unit D24 is expressed as log{(plate count after test with antibacterial agent)/(plate count after test with blank material)}, and, generally speaking, when the value is −2 or less the agent is evaluated as having an antibacterial effect. It is obvious from the figure that the developed product has a suffi-

Table 3 Characteristics of orange peel surface prepainted sheets

	Description
Advantage	· Damages during transport and work are not conspicuous. · Basic properties of the film are the same as the smooth surface product. · Mean film thickness is the same as the smooth surface product. · Finishing is similar to post-coated sheets and mixed use makes no problem.
Problem	· Some finish coat materials do not form the orange peel appearance easily.

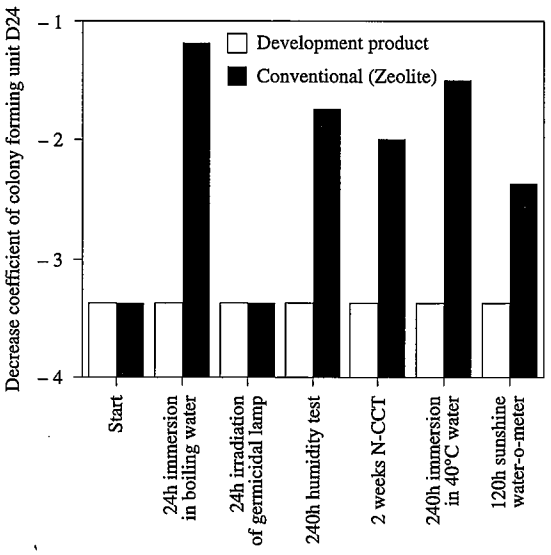

Fig.8 Preservation of germicidal effects of antibacterial prepainted sheets

ciently high germicidal capacity against colitis germ and capable of maintaining the faculty under widely varied environmental conditions.

4.3 Deep drawing[20]

Bending and drawing are typical of forming works of steel sheet products. Bending is most widely used for home electrical appliances and some investigations have reported the relationship between paint coat properties and bendability. Plotting of tensile strength and elongation of coating materials is shown in **Fig.9** classifying various kinds of prepainted sheet products with different coating materials by formability. For example, Δ represents a group capable of withstanding 0T bend having a film elongation nearly 200%. Likewise, a film having an elongation about 150% can undergo 1T bend and the one with 80 - 160% elongation allows for 2T to 3T bend. The larger the elongation the better the formability[21]. It is also observed that films of high tensile strengths offer better bendability even with low elongation as seen typically in the 1T group (□) and 4 - 5T group (◆).

Some home appliances such as lighting apparatuses require deep drawing work. Deep drawing is essential for the automobile parts, which constitute a new promising field of application for the prepainted sheets. Few studies have been done, however, on the relationship between paint film properties and deep-drawability. The authors carried out a study in this respect[22].

Fig.10 shows the relationship between the paint film elongation and stress. A primer film was formed on hot dip galvanized sheets and four different kinds of paint films were formed thereon. Then the prepainted specimens thus prepared underwent cup tests of square and round sections in accordance with the conditions described in **Table 4**, and the damages of the paint coat were inspected. **Fig.11** shows the observation results. The films C and D were wrinkled and peeled off at the square cup test despite their high elongation and good bendability, which fact clearly told that deep-drawability could not be accounted for by the film elongation.

At this, the authors calculated elastic strain energy of the films and investigated its relationship with drawability. The elastic strain energy was calculated in the following manner: the paint film was elongated by 40%, then the cross head was slid back in the shrinking direction until the load became 0. The load and elongation/shrink-

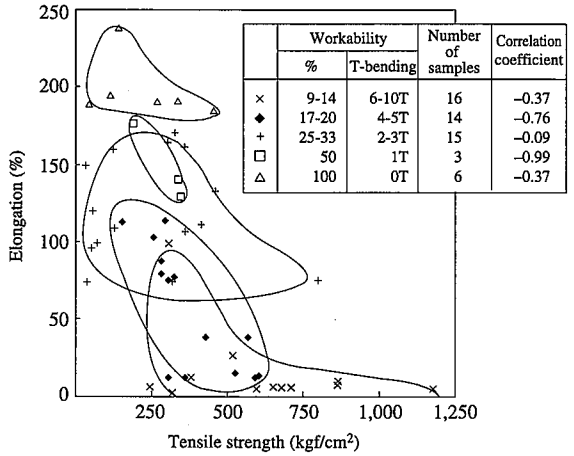

Fig.9 Effects of tensile strength and elongation of coating films on T-bend formability

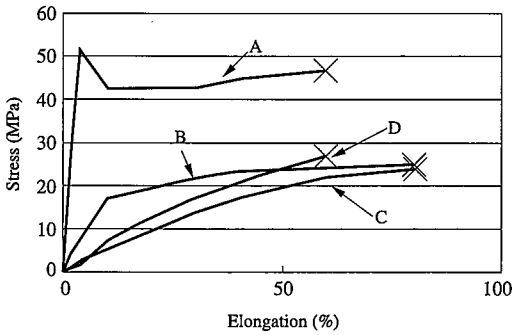

Fig.10 Mechanical properties of paint films used in drawability test

Table 4 Conditions for drawability test

	Square cup test	Round cup test
Punch shoulder radius	3 mm	3 mm
Die shoulder radius	3 mm	3 mm
Punch size	70 × 70 mm	50 mmϕ
Blank size	140 × 140 mm	100 mmϕ
Forming height	30 mm	Draw out

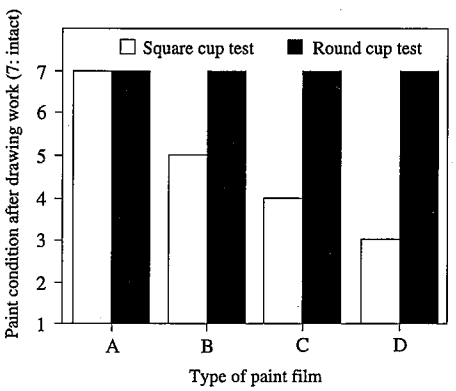

Fig.11 Damages of different paint coats after drawability test

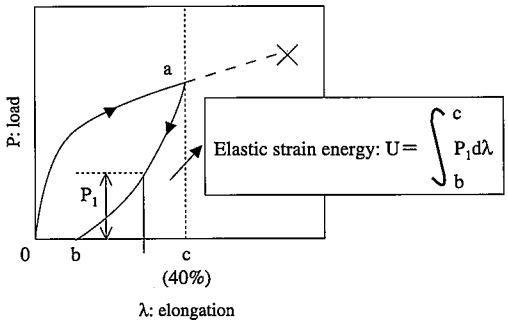

Fig.12 Measurement method of elastic strain energy

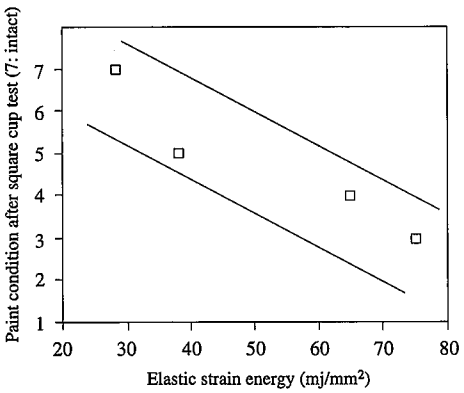

Fig.13 Relationship between elastic strain energy and paint film damage after square cup test

age amounts were measured all through this process, and then the elastic strain energy was calculated according to **Fig.12**. **Fig.13** shows the relationship between the elastic strain energy and the paint film damage after the square cup test. It is observed that the smaller the elastic strain energy the better the deep-drawability of the film, suffering the less damages (wrinkles and peeling off). This is presumably because the elastic strain energy accumulated in the film is used for peeling it off from the metal surface.

When prepainted sheets with paint films having low elastic strain energy like A and B of Figs.10 and 11 are square cup tested as described in Table 4, cross cut, then salt spray tested for 500 hrs, no paint peeling was observed, while the specimens using the films C or D having high elastic strain energy suffered paint peeling at the cross cut portion. Although no peeling occurred to any of the four kinds of films after only the round cup test, as shown in Fig.11, it is suspected that in a corrosive environment the paint film adhesion is weakened by corrosion. This facilitates peeling of the films having high elastic strain energy.

From these studies it was concluded that the films which have rather high elasticity modulus and yield elongation like the film A had low elastic strain energy and were suitable for drawing work. Based on this understanding a prepainted product having superior drawability was developed and has since been used for applications requiring deep-drawability such as lighting apparatuses and automobile oil filter casings, etc.

4.4 High weatherability[21]

A new prepainted sheet product with a new polyester resin film in which hindered piperidine structure effective for inactivating radicals causing photo degradation and cyclohexane structure for decreasing hygroscopicity of the film are incorporated in the molecules for enhancing weatherability of the product. Results of the sunshine

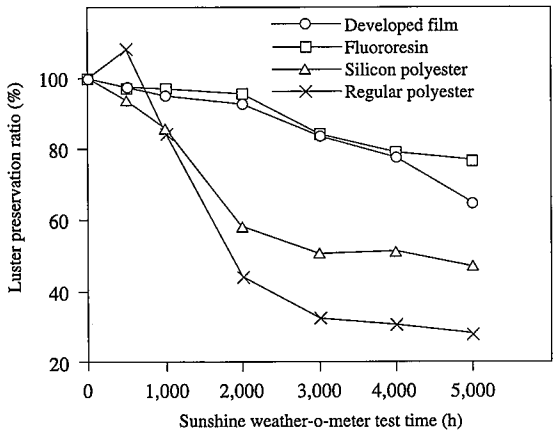

Fig.14 Sunshine weather-o-meter test of the new high weatherability film

weatherometer test of the developed product are shown in **Fig.14**. Weatherability of the developed paint film is considerably higher than ordinary polyester resins and silicon polyester resins, and it contends pretty well with fluororesin. Products with this coating material are being prepared for commercial applications to outdoor uses.

5. Conclusions

Development of technologies for correcting the shortcomings of the prepainted products and the latest technologies for giving new functions to the coating film were described above. Prepainted sheets are environmentally friendly products enabling the users to their omit painting processes. Naturally, various fields of industry will find it necessary to eliminate painting processes. The authors are ready to meet the challenges through close communication with the clients and efficient and timely technological development. Another paper is included in this publication focusing on the development of prepainted sheets where no chrome compounds are used. The authors would be happy if that paper is also found to be of interest.

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