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Development of Precoated Metal "RIVER PREC" for Home Appliances

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Synopsis :
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Development of Precoated Metal "RIVER PREC" for Home Appliances*1

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1 Introduction

In the post-coating method which was conventionally used by electrical home appliance makers and others, uncoated steel sheets such as cold-rolled sheets and coated sheets such as galvanized steel sheets were purchased and press- or roll-formed and then coated after degreasing and surface-treating.

In 1978, General Electric Co. of the U.S. adopted the so-called Precoated Metal (PCM) for home appliances which were precoated by steel makers with a film having specified coated film properties, so as to do away with coating facilities. General Electric Co. went even further to construct a refrigerator exclusive-producing plant having no coating-related facilities. An award won by General Electric Co. from the National Coil Coaters Association (NCCA) for this successful venture came to bring worldwide attention focused on PCM. PCM had been used before by General Electric Co. and some of Japanese home appliance makers, but the construction of an integrated plant having no coating line was epoch-making, and this news gave a strong stimulus not only to home appliance makers but also to coated steel sheets makers, thereby encouraging active studies on making PCM.

Kawasaki Steel took up the PCM development project in 1977 and started commercial production in 1978 with orders received for PCM to be used for refrigerators. The ensuing years saw a series of actively promoting improvements and developments of various PCM steels, paints and coating techniques. As a result, Kawasaki Steel is now producing high quality PCM (Tradename: **"River Prec"**) for wide applications such as a refrigerator shown in **Photo 1** and other home appliances such as washing machines and lighting fixtures.

2 Trends of Precoating

Spurred by the innovating GE activities as explained above and by rationalization needs such as for energy

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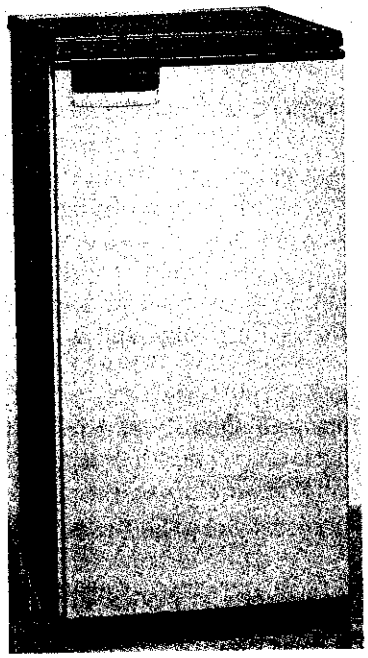

Photo 1 Application of RIVER PREC for refrigerator

saving and capital investment restraint, Japanese home appliance makers made active studies on PCM adoption.

To keep pace with the move of the home appliance makers, precoated steel sheets makers endeavored to develop high quality paints to withstand fabrication strain and to improve coating techniques in addition to the manufacturing techniques of color-coated galvanized sheets for construction materials which they had been manufacturing. Consequently PCM produced by precoated sheet makers have become satisfactory products which can fully withstand working by electrical home appliance makers and other users.

Figure 1 shows a comparison in fabricating process between PCM and post-coated material used by electrical home appliance makers; **Table 1** shows the merit and demerit of PCM[1,2]

Since PCM presupposes forming work, flexibility of the coated film becomes an important quality item. In general, however, when the flexibility of the coated film is improved, the film becomes softer, and quality such as stain resistance tends to drop.[3] For this reason, it was impossible at an initial period of PCM development to reconcile the flexibility of the coated film with hardness (scratch resistance) and stain resistance. Therefore, home appliance makers were compelled to take the following measures at the time of adopting PCM:

(1) Consideration is given to the product design, so that the degree of working will be reduced.
(2) Warm working is performed to prevent paint film cracking in fabrication.
(3) To prevent the product from being scratched during working and assembling, the conveyor table, and others are lined with rubber or felt.

Subsequently research and development activities were vigorously conducted by the precoated steel sheet makers and paint makers, resulting in the development of a polyester resin paint PCM of excellent workability whose coated film was nearly equal to the post-coated film in hardness and stain resistance. Evaluation of PCM in recent years is as follows:

Table 1 Characteristics of precoated metals when applied to the usage in home appliances

Merit	Demerit
1 Coating equipment is not necessary.	1 Corrosion resistance of shear and punched section is inferior.
2 Pollution prevention is not necessary and working environment is improved.	2 Spot welding is not applicable.
3 Maintenance cost is relatively small.	3 Prone to scratches during handling and forming.
4 Space of layout is small.	4 Products design is limited because of formability and weldability.
5 Saving materials and energy.	
6 High productivity is possible.	

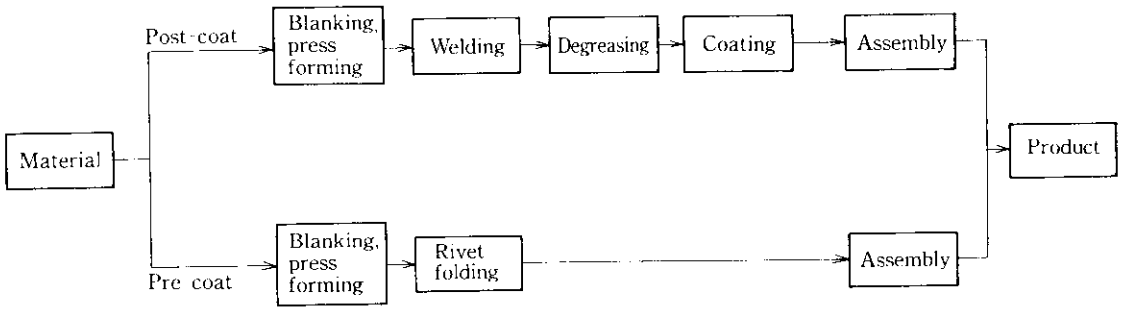

Fig. 1 Comparison of fabricating processes of PCM and post-coating material

(1) Finish coat is smooth and has pleasing appearance.
(2) It has workability which can withstand roll forming, bender working and press forming.
(3) The coated film has adequated pencil hardness and stain resistance.
(4) It is also coated on the reverse side, thereby effectively preventing the reverse side from rusting.
(5) Since no coating line is required, it is possible to reduce the equipment cost burden, energy consumption, work processes and running inventory. It can also make great improvements in environmental preservation and public pollution prevention.

It is considered, therefore, that application of PCM will be more expanded in the future. Already some electrical home appliance makers in Japan are operating factories which use virtually PCM alone.

3 Quality Level Required of Precoated Metal for Home Appliances

Table 2 shows the quality level required, for instance, of PCM for refrigerators, and performances of River Prec and color-coated galvanized sheets for construction materials both of which are manufactured by Kawasaki Steel. PCM for home appliances are required to have qualities of much higher levels in workability, external appearance, flatness than those of color-coated galvanized sheets for use in roofing and walls.

4 Manufacture and Quality of River Prec

4.1 Manufacturing Process

River Prec is coated using the 2-coat, 2-bake method

Table 2 Required performance characteristics for PCM and the property of RIVER PREC

Test-items \ Class / Paint type	Required performance characteristics (for refrigerator)	River prec		Ordinary pre-painted galvanized sheet (JIS G 3313)
	Polyester	Acrylic	Polyester	Polyester
External appearance	◎	◎	◎	○
Dry film thickness (μm)	20~30	20~30	20~30	15~20
Pencil hardness	H~2H	2H~3H	H~2H	H~2H
60° gloss (%)	≧80	80~85	80~85	50~70
Cross scoring test (JIS G 3313)	◎	◎	◎	◎
Impact test (cm) (the Du Pont type impact tester 12.7 mmφ × 500 g)	≧50	20	≧50	40
Flexibility (min. bend radius) (No visible cracking of paint film on outside radius after bending (t=sheet thickness))	1t	3t	1t	2t
Stain resistance	◎	◎	◎~○	○~△
Salt spray resistance (5% NaCl 35°C × 240 h)				
Creep	◎	◎	◎	○~△
Blistering	◎	◎	◎	◎
Humidity resistance (R.H. 90% 50°C × 192 h)	◎	◎	◎	◎
Hot water resistance (90°C up × 1 h)	◎	◎	◎	◎~○
Detergent resistance (0.5% synthetic detergent 40°C × 72 h immerse)	◎	◎	◎	◎
Alkali resistance (5% NaOH 20°C × 24 h immerse)	◎	◎	◎	◎
Acid resistance (5% H_2SO_4 20°C × 24 h immerse)	◎	◎	◎	◎
Toluene resistance 1 h immerse	◎	◎	◎	◎

◎: Excellent, ○: Good, △: Fair

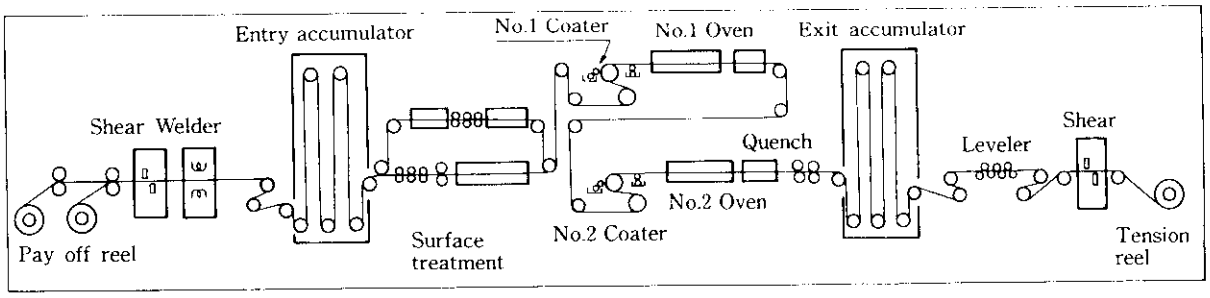

Fig. 2 Schematic diagram of coil coating line

on the continuous color coating line (CCL). After coating, River Prec is coiled and subjected to slitting, sheet cutting, or surface-protective film lamination, according to specifications by electric home appliance makers, before it is shipped. **Figure 2** shows a schematic diagram of the coil coating line at Hanshin Works.

4.2 Stock Sheets

4.2.1 Type of steel sheets

River Prec uses the following steel sheets as standard:

(1) Hot dip galvannealed steel (River Alloy)
(2) Hot dip galvanized steel (River Z, non-alloy type)
(3) Electrolytic Zn-coated steel (River Zinc)
(4) Zn-Ni electroplated steel (River Hizinc)
(5) Cold rolled steel

In recent years, River Alloy which has excellent coated film adhesion, corrosion resistance at end surfaces and excellent coated finish is more frequently used.

4.2.2 Surface appearance

In general, the post-coat is made into a thick film of about 40 to 50 μm by electrostatic-coating and the surface after coating has the so-called orange-peel finish, and therefore minute defects on the original steel sheet surface can be easily covered by coating. Whereas PCM is roll-coated, resulting in a film thickness of only 20 to 30 μm and a smooth coated finish. Consequently, minute deviation and defects on the steel sheet surface will appear as coating defects such as uneven brightness and irregular color. To prevent these coating defects, some special control standards have been set up on the following points in the manufacture of PCM steel sheets:

(1) To prevent roll marks, scratches, and the like, from occurring during hot and cold rolling.
(2) To prevent seams and ashes from occurring during hot dip galvanizing.
(3) To inspect various rolls and sheet surfaces.

4.2.3 Surface roughness

Surface gloss is an important item in PCM properties.[4] One of the factors which affect the gloss is surface roughness of the steel sheet. As shown in **Fig. 3**, a correlation exists between the average surface roughness (R_a) of the steel sheet and the gloss of the coated surface, and the smaller the average steel sheet surface roughness, the more improved is the gloss, when the same resin paint is used. Therefore, the average surface roughness of the steel sheet is controlled within an adequate range. One of these control methods is proper selection of roll surface roughness and the amount of screw down during the skinpass rolling of the steel sheet.

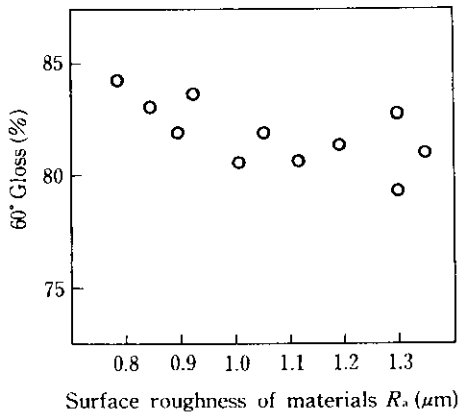

Fig. 3 Relation between gloss of coated film and surface roughness

4.2.4 Plating quality

Hot dip galvanized steel sheets pose problems in the cracking and powdering of zinc at the portion worked. The reason for this is that since PCM is fabricated after coating, resistance to peeling and corrosion of the coated film is affected by working. Therefore, zinc composition at hot dip galvanizing is controlled, and for River Alloy, alloying is controlled within the optimum

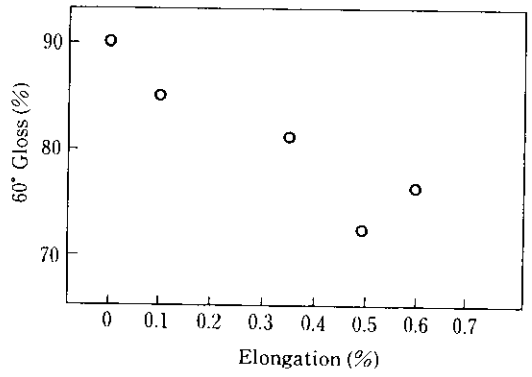

Fig. 4 Relation between gloss and elongation by tension leveler on CCL

range. These steel sheets are used only after careful checking before coating by special tests and judging method of finding their suitability to PCM.

4.2.5 Quality of PCM steel sheets

Steel Sheets used for PCM are divided into commercial quality steel and non-aging steel according to their uses. Coated steel sheets are baked at 200 to 250°C. As a result, steel sheets of commercial quality deteriorate by aging, and sometimes develop stretcher strain and fluting during working. An ordinary measure to be taken to prevent such defects is leveler treatment. However, leveler treatment causes a ripple-shaped irregular-height pattern called the chatter mark, resulting in deterioration of the gloss and external appearance level. These defects are not suitable for uses which require particularly pleasing appearance such as for refrigerator doors. **Figure 4** shows an example of gloss deterioration trends of polyesterbased, coated film when material elongation has occurred by leveler treatment at the CCL line, and indicates a great effect of elongation on the gloss. In such a case, non-aging sheets which require no leveler treatment are used.

4.3 Coated Film Design

Coated films for PCM are broadly divided into that which uses an epoxy-resin-type primer and an acrylic-resin-type top coat with importance attached to hardness and stain resistance of the coated film, and that which uses polyester resin for both the primer and top coat with emphacis placed on workability. After improvements have been made on resins, a highly workable polyester-resin-type coated film, which has both excellent coated film hardness and stain resistance, is now mainly used. There are many points which require caution in the coated film design, and some of them are briefly described below.

(1) To obtain a high degree of balance between workability, hardness, and stain resistance, through the use of a softer and highly workable primer and harder high-stain-resistant top coat.
(2) To obtain stabilized color tone by harmonizing the respective colors of the primer and top coat.
(3) The surface gloss is governed by the coating resin used, in addition to the aforementioned steel-sheet surface roughness. Paint consists of a base resin, color pigment, and various additives. In general, as the pigment mixing ratio to the base resin is increased, the gloss deteriorates. In light-tone colors, particularly in white, the quality of the pigment to be mixed into the base resin is increased to improve the hiding power of the coated film, and therefore special caution is required in selecting the kinds, particle sizes, degree of dispersion and orientation of pigments, and in using special types of additives.
(4) To accentuate their product designs, electric home appliance makers sometimes print on the PCM coated film. Cut edge and scratched portions also are touched up. These repaires are related to solvent resistance of the coated film and its adhesion to the toutched-up coat. Such matters must be confirmed at the time of the coating material design.
(5) When deep coloring of red, black, and blue is used, the coated film becomes softer due to the nature of pigments used, and shows the trend of making the flaw on the coated film conspicuous.[5] Therefore, attention should be given to the selection and blending of resins.

In making the coated film design, the above-mentioned matters are taken into consideration, and a system has been established which meets the quality requirements by electric home appliance makers.

4.4 Types of Coated Films and Properties of Worked Portion of PCM

Figure 5 shows the relation of surface cracking to the kinds of steel sheets and difference in elongation.

In hot dip galvanized-type steel sheets, crack width tends to become wider, as the zinc deposition increases. **Figure 6** shows the occurrence of cracking after these steel sheets are coated and bent. The figure indicates that the acrylic resin coated film with low ductility has a wider crack, but the polyester resin coated film with high ductility covers the cracking of steel sheets to a certain degree.

Figure 7 shows the results of salt spray test on a cold worked portion. The figure indicates that the acrylic resin coated film develops a wider crack and, consequently, shows a large rust formation, but if a hot dip galvanized-type steel sheet is used, the rust formation improves to a certain extent. In the polyester resin coated film, no crack or only a very fine crack has occurred on the coated film. Therefore, a slight rusting is only

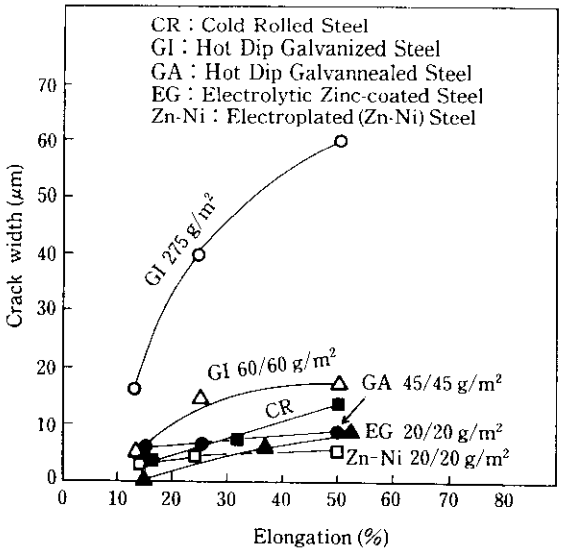

Fig. 5 Relation between elongation and crack width of surface treated steels

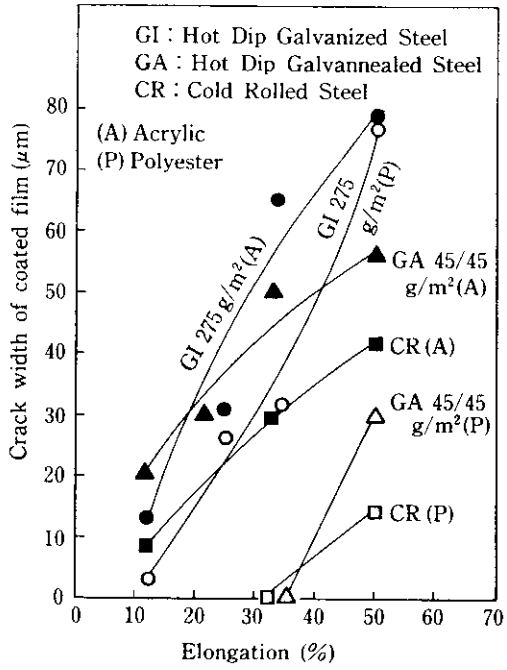

Fig. 6 Relation between elongation and crack width of coated film on surface treated steels

found even on cold rolled sheets, but no rusting is observed when hot dip galvanized-type steel sheets are used.

Namely, resistance against corrosion including crack occurrence at the worked portion can be improved by the use of hot dip galvanized-type steel sheets, but a steel sheet with thicker zinc deposition develops wider cracking on its zinc-plated layer, thereby causing deterioration in corrosion resistance. In such a case, it is effective

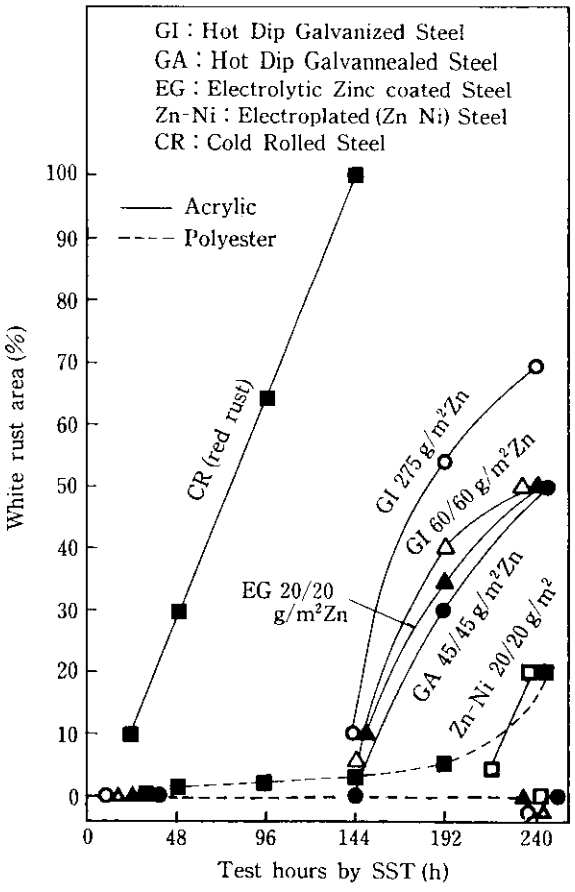

Fig. 7 Rust formation on the outside part bent at the radius of $1t$ in salt spray test

to use polyester resin coated film which can cover the crack on the steel sheet by the elongation of the coated film.[6] There is a limit, however, to such elongation of the coated film, and when the degree of working becomes severer, the polyester resin coated film also develops cracking. The width limit of coated film cracking which affects corrosion resistance at the 240 h salt spray test is 10 μm for cold rolled sheets and about 30 μm for hot dip galvanized-type steel sheets. Therefore, if the crack width is reduced to below the abovementioned values, corrosion resistance of the worked portion can be maintained.

When the crack occurrence limits of the steel sheet and coated film are to be exceeded in the product design and working, the use of warm working process is effective.[4] **Figure 8** shows the resuslt of the 180° bend test to investigate crack occurrence of the coated film due to bending depending upon the differernce in testing temperatures. When the testing temperature is 50°C, the working limit improves by about $0.5 \sim 1t$ (t = sheet thickness) in the minimum bend radius, compared with the case of a testing temperature of 20°C. This indicates that if warm working is used, crack occurrence in the

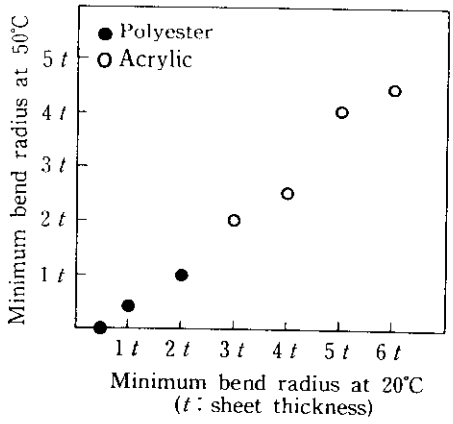

Fig. 8 Effect of testing temperature on the bending limit without crack in 180° bend test

coated film is reduced, and consequently corrosion resistance of the worked portion improves, the worked product being equal; therefore, even PCM made of cold rolled steel sheets can be used with full satisfaction for some applications, if consideration is given to the coating film resin, product design (degree of working, treatment of cut edge, etc.) and warm working.

4.5 Types of Standard Coated Films

River Prec is manufactured by the 2-coat, 2-bake coating method, and in order to fully use its aforementioned coated film properties and to accommodate diversified quality requirements, the following standard coated film types have been made available:

(1) High workability type which attaches importance to workability (type A)

(2) Balanced type which harmonizes workability, coated film hardness, and stain resistance (type B)

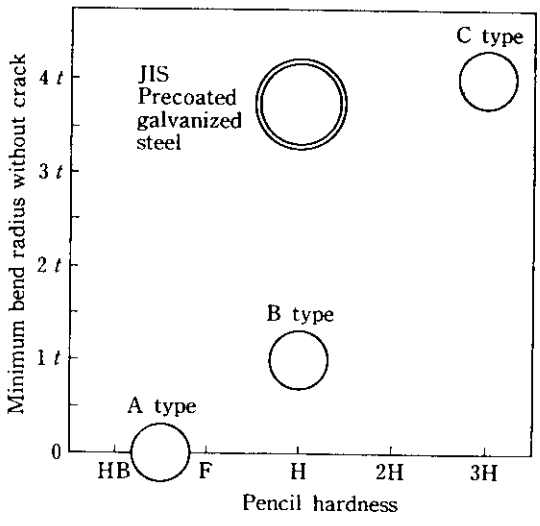

Fig. 9 Relation between pencil hardness and bending property of paint systems

(3) High hardness type which attaches importance to scratch and stain resistance (type C)

Figure 9 shows the relation between pencil hardness and bending properties of such standard coated films. The future target of development is aimed at PCM in which the balance type is further improved to achieve excellent workability, a harder coated film, and excellent scratch and stain resistance.

4.6 Dust-Proofing of Coating Line

During the coating and baking processes, various types of dust are liable to deposit on the coated film. Such dust is called the dust spot and posses problems in external appearance and corrosion resistance, thereby making dust preventive countermeasures very important.

4.6.1 Occurrence sources of dust spot

Ingredients, concentration and modes of the dust spot was analysed in detail at various parts of the CCL, and effective atmosphere-cleaning measures were taken against major dust sources such as the interiors of the baking oven and coating room and inclusion of settling dust.

4.6.2 Outline of atmosphere cleaning

(1) Oven

The coated film is bake-hardened by blowing combustion gases to steel strip in the oven, and part of this hot wind is recirculated. Various heat insulation materials used in the combustion chamber and oven are deteriorated due to exposure to the hot wind, fall off, and are mixed as dust into the circulating gas, thereby causing dust spots. Therefore, ingenuity is used on the adiabatic structure and its materials to prevent them from deteriorating and falling off. Further, to prevent dust from generating and concentrating in the circulation gas, a combustion gas circulating system unique to Kawasaki Steel has been developed through the analysis of the combustion circulating gas. This new system permits further improvement in cleaning the combustion gas in the future, and the system also is effective in achieving energy saving.

(2) Coating room

Dust spot generation in the coating room amount to 40% of the total. This problem was solved by sending filtered clean air into the air-proof coating room and by introducing the coater outdoor remote control systems.

(3) Settling dust

Since the space between the oven outlet side and the tension reel on the CCL is opened, floating dust in the building settles down to make dust spots. To cope with this settling dust, the space after the oven outlet side on the CCL was covered with a special structure to ensure the cleanliness of the inside atmosphere.

Through the adoption of these clean-air measures, the generation ratio of dust spots decreased to 1/5 of the level before the modification, thereby making it possible to meet the end use which has strict quality requirements for external appearance.

4.7 Other Countermeasures

The requirements for product appearance of PCM are very strict as mentioned before, and even a slight handling scratch is not permitted. Even after coating and coiling at the CCL, there are many occasions to handle PCM sheets such as slitting and sheet-cutting depending upon requests by electric home appliance makers. In these steps, measures suitable for PCM manufacture are taken to effect integrated quality and process control. One example is a consideration given to the reverse surface service coating material in respect of its hardness, blocking resistance, and sliding friction property in order to prevent scratching on the guaranteed surface during product handling.

5 Concluding Remarks

Six years have passed since "River Prec" was first produced as precoated metal (PCM) for home appliances succeeding the production of color-coated galvanized sheets. Unlike the construction-material sheets, PCM products are required to have high quality in surface appearance, workability and other properties, and the required properties themselves widely vary with each electric home appliance maker and each purpose of use. To meet such diverse requirements, Kawasaki Steel has developed steel sheets, paints, and manufacturing techniques, backed by a fully-integrated process control and quality control system. As a result, Kawasaki Steel has established a system for manufacturing PCM which has an excellent workability, resistance to scratch and stain, and a pleasing surface appearance.

Kawasaki Steel is endeavoring to improve PCM toward a still better workability and a higher resistance to scratch and stain.

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