KAWASAKI STEEL TECHNICAL REPORT
No.8 (September 1983)

An Outline of New Electrogalvanizing Line (KM-RCEL)

Akira Komoda, Yasuhiro Hirooka, Kazuaki Miyachi, Takahisa Yoshihara, Akira Matsuda, Hisao Yasunaga, Hajime Kimura

Synopsis :
A new electrogalvanizing line started its operation in January, 1982 at Chiba Works, Kawasaki Steel Corporation. Named KM-RCEL (Kawatetsu Multipurpose Radial Cell Electroplating Line), the new line has since been achieving successful production. For the plating process, "CAROSEL" developed by U.S. Steel was selected for the sake of its technical potentiality and economic advantage. KM-RCEL is the world's first trial of both-side coating utilizing U.S. Steel's "CAROSEL" process. Kawasaki Steel has incorporated its own ideas and developments, thus enabling the manufacture of both-side products of excellent quality. As for one-side coating, "Perfect one-side" products are easily obtained as expected, and the uncoated surface has no throw-around of zinc which was unavoidable in conventional plating methods. This paper presents a brief introduction of KM-RCEL, putting stress on plating process, together with data on the qualities of its products. Features of this line are as follows: (1) A great saving in electric power consumption (2) A markedly easy operation using a unique consumable anode system (3) An attractive appearance of products with higher luster (4) Various facilities of post treatment for wide range of application (5) A large capability for future expansion.

The body can be viewed from the next page.

An Outline of New Electrogalvanizing Line (KM-RCEL)*

Akira KOMODA** Yasuhiro HIROOKA** Kazuaki MIYACHI**
Takahisa YOSHIHARA** Akira MATSUDA** Hisao YASUNAGA**
Hajime KIMURA***

A new electrogalvanizing line started its operation in January, 1982 at Chiba Works, Kawasaki Steel Corporation. Named KM-RCEL *(Kawatetsu Multipurpose Radial Cell Electroplating Line), the new line has since been achieving successful production.*

For the plating process, "CAROSEL" *developed by U.S. Steel was selected for the sake of its technical potentiality and economic advantage.* KM-RCEL *is the world's first trial of both-side coating utilizing U.S. Steel's* "CAROSEL" *process. Kawasaki Steel has incorporated its own ideas and developments, thus enabling the manufacture of both-side products of excellent quality.*

As for one-side coating, "Perfect one-side" products are easily obtained as expected, and the uncoated surface has no throw-around of zinc which was unavoidable in conventional plating methods.

This paper presents a brief introduction of KM-RCEL, *putting stress on plating process, together with data on the qualities of its products. Features of this line are as follows:*

(1) A great saving in electric power consumption
(2) A markedly easy operation using a unique consumable anode system
(3) An attractive appearance of products with higher luster
(4) Various facilities of post treatment for wide range of application
(5) A large capability for future expansion.

1 Introduction

Completed in January 1982 at the No. 2 Cold Rolling Plant, Chiba Works,. the electrogalvanizing line named KM-RCEL (Kawatetsu Multipurpose Radial Cell Electroplating Line) has since been operating smoothly. This is Kawasaki Steel's second electrogalvanizing line, following the first one at its Hanshin Works, and expected to meet rising demands in this field, especially growing requirements for higher product qualities and better performances.

As the plating system, the CAROSEL(Consumable Anode Radial One-Side Electroplating; Trademark of the U.S. Steel Corporation) was selected from among a number of existing plating processes[1-7] in consideration of economy and technical potentiality in future. By incorporating Kawasaki Steel's own developments[8-11], KM-RCEL is the realization of an electroplating line of far-ranging application and potential.

The basic design concept of the line extensively pursued the conservation of energy and resources, and labor saving through automatization, while consideration was given to ample flexibility in meeting future demand increases and diversifying requirements for higher product quality and new product developments.

This paper introduces an outline of KM-RCEL and the features of product qualities.

2 Line Configuration

A schematic and an overall view of the KM-RCEL are shown in **Fig. 1** and **Photo 1**, respectively.

2.1 Basic Specifications

(1) Production capacity
20 000 t/month
(2) Material coil
Cold rolled coil after tempering
Hot rolled coil after pickling

* Originally published in *Kawasaki Steel Giho*, **15** (1983) 1, pp. 1-9
** Chiba Works
*** Research Laboratories

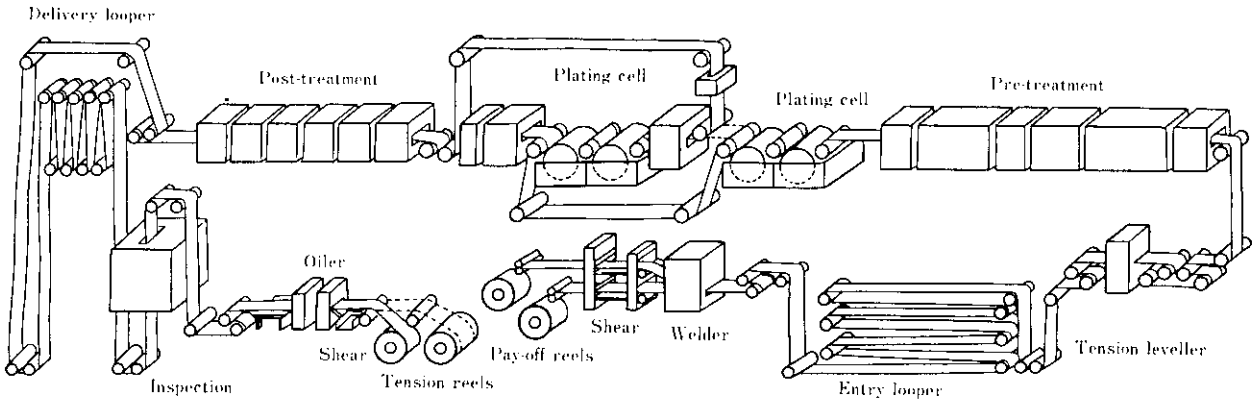


Fig. 1 Schematic diagram of KM-RCEL

Photo 1 General View of KM-RCEL

(3) Dimensional ranges
Sheet thickness: 0.4 — 1.6 mm
Sheet width: 750 — 1 600 mm
(4) Product coil
Weight: 25 t (max.)
Outside diameter: 2 134 mm (max.)
Inside diameter: 508 mm, 610 mm
(5) Line speed
Entry section: max. 150 m/min
Center section: max. 120 m/min
Delivery section: max. 150 m/min

(6) Plating cell
4 cells, radial type
(7) Rectifier for plating cell
12 500 A × 20 V × 8 units

2.2 Manufacturing Process

The principal manufacturing process is shown in **Fig. 2**.

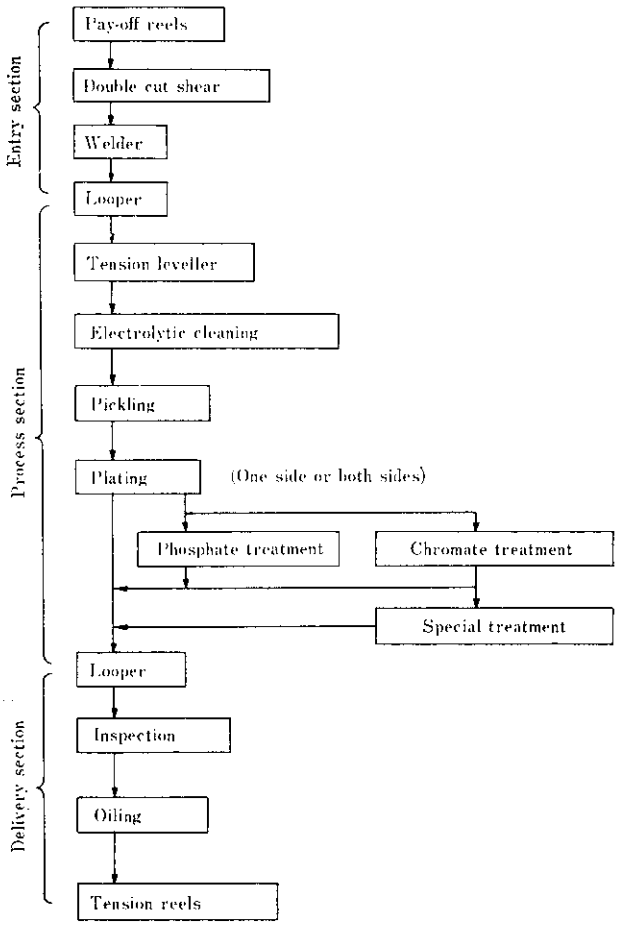


Fig. 2 Manufacturing process

2.3 Entry Section

A material coil is brought into the coil skid by the overhead travelling crane and loaded onto the pay-off reel automatically. The unwound portion of the leading end is levelled by the pay-off leveller to eliminate coil set, with off-gage portion automatically cut off by the double-cut shear and is sent to the welder.

The trailing end of the preceding coil automatically slows down and comes to a stop at a preset level of coil layers or at any off-gage portion which is cut off as specified. The preceding coil is welded to the leading end of the following coil. After punching for tracking weld point and notching, the strip is fed into the entry loop car.

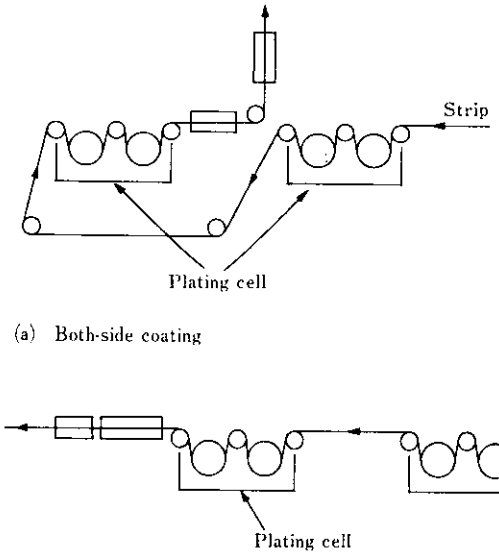
2.4 Center Section

(1) Tension leveller
In general, it is desirable to install a tension leveller close to the tension reels so as to avoid possible deforming in the line. In case of the electrogalvanizing line, however, levelling after plating and chemical treatment will degrade the surface appearance. For this reason, in KM-RCEL, the tension leveller is placed at the entry side of the center section. With diameters and crowns of rolls in the line properly selected and the set-up accuracy of rolls kept high, products of satisfactory shape can be obtained from such layout.

(2) Cleaning
Since plating adhesion is markedly affected by the degree of surface cleanliness in the electrogalvanizing process, cleaning is a very important step. In KM-RCEL, scrubber units are installed before and after the electrolytic cleaning unit, so that contaminants on the sheet surface can be removed completely by the combined functions of these units.

(3) Pickling
The purpose of pickling in the electrogalvanizing process is to activate the sheet surface prior to plating in a relatively short treatment time. In KM-RCEL, pickling is performed with the hydrochloric acid soaking which ensures beautiful surface finish.

(4) Plating
Plating is performed with 4 plating cells of radial type equipped with large diameter conductor rolls. Since this arrangement inevitably turns out one-side coating only, the strip must run through different paths, as shown in **Fig. 3**, depending upon one-side or both-side coating. In comparison with the conventional plating equipment, the number of cells is reduced, because the radial type cell allows the use of large current, which is 25 000 A/cell at present, and expected to be 50 000 A/cell in future. Inadequate rinsing after plating tends to cause surface irregularities, giving unfavorable effects to chemical treatment and surface quality of the products. In KM-RCEL, the wash and wringer system is adopted to upgrade the rinsing effect, and the 4-stage cascade system is used to save spray water consumption.
The zinc coating weight is automatically controlled using a fluorescence X-ray plating thickness gage installed in the line after rinsing and drying.



(a) Both-side coating

(b) One-side coating

Fig. 3 Two types of strip pass through plating cells

(5) Chemical treatment
In the present product mix, a majority of the products are subjected to chemical treatment, such as phosphate or various chromate treatments, which are performed by a selective use of a number of horizontal treatment tanks. The selection is remote-controlled through the automatic mechanism. The line consists, from the entry side in the direction of strip travel, of conditioning, phosphate treatment, chrome treatment, rinsing, sealing, roll coater and dryer. After the chemical treatment, the strip is led to the delivery looping tower.

2.5 Delivery Section

The strip leaving the delivery looping tower passes through the inspection room, is oiled, if necessary, by the electrostatic oiler, cut off by the flying shear and coiled on a tension reel. A series of delivery side operations, such as automatic speed-down upon detecting welded portion or instructions for coil

cutting, coil unloading and weighing, are carried out automatically.

The weighed coil is loaded onto a cart by the overhead travelling crane and carried to the coil packaging workshop in the adjacent yard.

The delivery section includes inspection instruments such as γ-ray thickness gage, pinhole detector and ultrasonic flaw detector, and indicators such as differential thickness marker and sheet mark printer, all installed in the line.

The inspection room is located at the vertical pass on the delivery side of the looping tower, so that the both sides of strip can be readily subjected to the visual inspection. At the inspection room, outputs from inspection instruments in the delivery section are collectively displayed and inputted to the process computer for the centralized management of data processing.

3 Plating System

The plating system in the KM-RCEL is utilizing the CAROSEL developed by the U.S. Steel Corp.

3.1 Outline of CAROSEL

Figure 4 shows schematically the concept of plating cell and conductor roll in the CAROSEL system. The strip wound around a large-diameter conductor roll

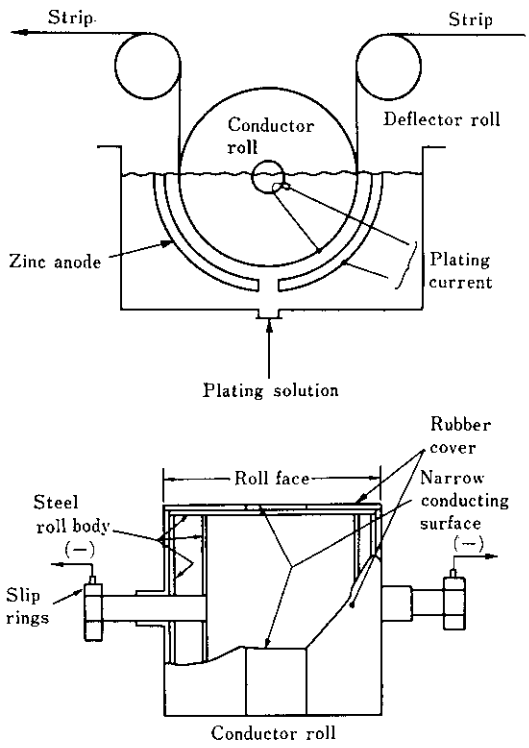


Fig. 4 Schema of zinc electroplating cell

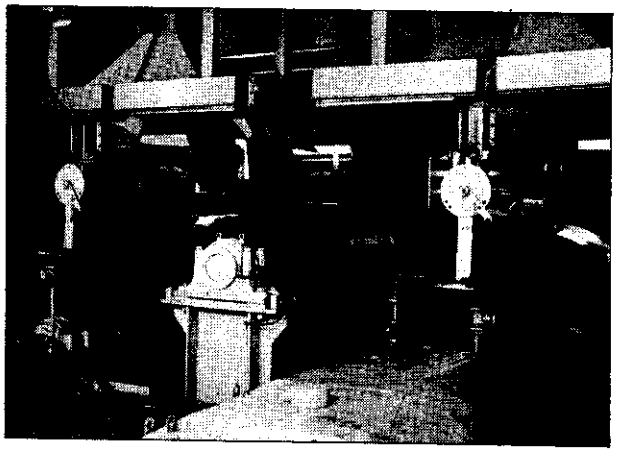


Photo 2 Plating cells and conductor rolls

is soaked in the plating bath. Plating is effected by applying current between the strip (cathode) and arch-shaped zinc anodes placed parallel to the strip surface. The conductor roll is of special construction with a metal conductor ring at the middle of the roll drum and rubber linings at both ends. **Photo 2** shows an outer view of plating cell and conductor roll.

Zinc anode consists of castings 160 mm wide, loaded in a row on the tilted anode bridge. The anode-to-strip gap is always held nearly constant with a horizontal pushing mechanism so as to compensate consumption of anode due to plating.

Plating solution is supplied to the bath between the strip and the anode from the cell bottom.

3.2 Features of CAROSEL

(1) Both-side plating in each side sequence
Essentially, only one side is plated in the cell; therefore, the strip is reversed and plated in another cell when the other side is to be plated, as shown in **Fig. 3**(a).

(2) No zinc deposition on the uncoated side
A special construction of the conductor roll causes both edges of strip to be sealed by rubber, preventing the uncoated side of strip from contacting plating solution to invite zinc "throw-around". **Figure 5** shows the zinc deposition on the uncoated surface of one-side plated steel strip. It is evident that the system completely excludes zinc throw-around, which has been inevitable in the conventional processes.

(3) Lower plating voltage
Since the strip pass in the plating cell is held stable by the advantage of conductor roll, it is possible to reduce the anode-to-strip gap by setting the anode closer. Moreover, as highly conductive chloride solution is used as plating solution, the

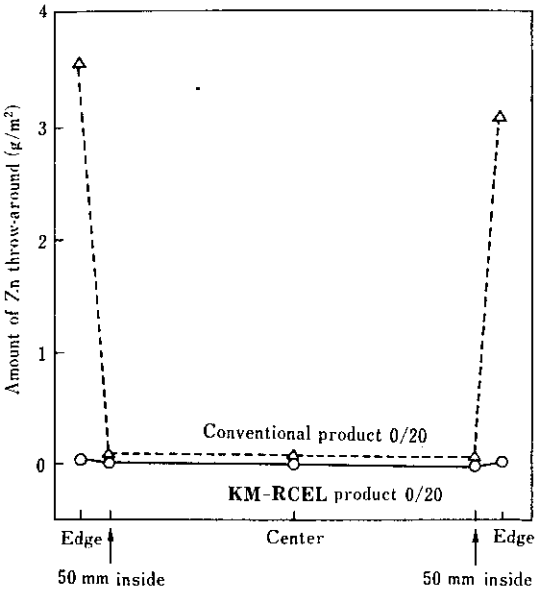


Fig. 5 Throw-around on uncoated surface of one-side electrogalvanized strip

electric resistance of this process is very low, and hence, the plating voltage is extremely low. In practice, the plating voltage is about 7 V for the current density 100 A/dm². For this reason, the power consumption for plating is reduced to 1/3–1/4 of that in the conventional process.

(4) High current density and large current
Because chloride by nature allows a high current density operation with a sufficient flow of solution between the anode-to-strip gap, plating at current density as high as 150 A/dm² is attainable. Besides, as the contact area between the conductor roll and the strip is extremely large, it is possible to use 50 000 A or greater current per cell. The equipment is, therefore, compact with the number of cells noticeably small for the current capacity.

(5) Soluble anode made easy to handle
CAROSEL has completely eliminated the problem of heavy muscle work required for anode adjustment in the conventional soluble anode system, yet it dextrously retains the merits of the soluble anode system in avoiding gas emission, contamination with impurities and troublesome control of bath concentration, all that accompany the insoluble anode system, thus permitting a stable and efficient plating.

3.3 KM-RCEL's Wide Application

As stated in the preceding subsection, the CAROSEL system is an excellent plating process, which has been developed originally for the mass production of one-side heavy plating for automobile use. The system has never been applied to other purposes, such as both-side plating and appearance-oriented light plating, and its adoption in KM-RCEL involved unknown fields.

Kawasaki Steel has introduced the CAROSEL system in recognition of its technical potential. Kawasaki Steel has widened the range of its applications by incorporating in it the results of the company's own research, thus attaining a high product quality, that satisfies ever-diversifying customer needs. Some of improvements and prospects for the future will be described below.

(1) Both-side plating
In the both-side plating in each side sequence, it is a general tendency that unevenness occurs between one-side and the other in terms of coating thickness, appearance and color tone because of dissolution and stain of the pre-coated surface. In KM-RCEL, it has become possible to achieve both-side plating of excellent whiteness, with no difference in color tone between them, through the improvement of bottom-bypass solution and keep-wet solution, and an appropriate control of conductor rolls.

(2) Anode profile control
In case of products of strict appearance requirement, the product quality may be affected by a small difference in anode profile (profile of anode-to-strip gap) due to changes in the strip width. Kawasaki Steel has developed a special pusher and a hanger mechanism, and the anode pushing system using the process computer, to achieve a precise anode profile control. Consequently, it is not required to readjust the anode width when the strip width is changed, leading to a uniform and beautiful plating with no edge overcoat.

(3) Operation at low speed and high current density
As is well-known, there is the tendency toward a decline in critical current density when line speed is low. Under the new KM-RCEL, through improvements in the flow of plating solution over the strip surface, the development of a special nozzle and an improved circulation system, Kawasaki Steel succeeded in keeping the higher critical current density even under operation at very low speed.

(4) Chemical treatment of sheets plated in chloride bath
Since the chemical treatment of sheets plated in all-chloride solution involves a number of differences from that in the conventional sulfate solution, some technical innovations have been required. A variety of excellent chemical treatments have become practicable at present, owing

to the studies on quality control of plated surface, selection of chemicals and treating conditions suited for highly reactive plated surfaces and methods of maintaining treatment conditions.

(5) Duplex coating
The production of duplex coating having a different metal coating on each side is suited for the line with the sequential plating system. In order to achieve this, many improvements were necessary in equipment and processing conditions, such as solution supply system, intermediate rinsing and a surface wetting system.

Some of the wide applications developed for CAROSEL at Kawasaki Steel have been described above. In considering general trends in plating technology in the future, it is expected that the higher current density and the circulation of plating solution at higher speed and larger capacity will be pursued. In this case, holding strip pass stable will be the most difficult point for the equipment. In applying large current, the current capacity of the conductor roll becomes a serious limitation. The CAROSEL system has essentially solved these problems, possessing a marked advantage. Moreover, since the radial cell was originally developed as a insoluble anode system, it is possible to use the insoluble anode, whenever necessary.

Continued efforts will be made in expectation of further improvement of KM-RCEL, thus contributing to the development of a better plating process.

4 Features of Equipment

Other than the plating system, KM-RCEL has the following features:

4.1 Overall Layout

(1) The delivery section is placed close to the entry section so as to secure labor saving and to monitor the operation of both sections in one view from the main pulpit, as shown in **Photo 3.**

(2) The major operation and control functions are centralized at the main pulpit with a testing and analysis laboratory located also nearby.

(3) The center section is provided with space for future expansion of plating capacity and post-treatment facilities.

4.2 Automatic Switching of Chemical Treatments

Since a variety of chemical treatments are made in a single pass in the conventional system change-over of these treatments required extremely troublesome work. In KM-RCEL, On/Off control of pumps, valves and rolls are preset, so that any treatment can be selected automatically by a mode select switch. In order to prevent solutions from being mixed before and after switching, the rolls and tanks are rinsed automatically and a non-drip design is adopted. Zone switching corresponding to changes in the line speed is performed automatically. The operational condition of these equipment is displayed on the CRT in the pulpit. Time required for change-over is 1–2 min. in actual practice.

4.3 Automatic Solution Control System

For cleaning, pickling, plating and chemical treatment, chemical solutions used in KM-RCEL cover many types, giving importance also to the quality control of a large amount of rinsing water. The control items roughly involve temperature, volume and concentration.

In KM-RCEL, the concentration is detected and controlled mainly by using conductivity meter in combination with pH meter and hydrometer.

For replenishing chemicals, stock solution is used as far as possible, with feeding regulated by the control of operating duration of the metering pump. An example of automatic solution control system is shown

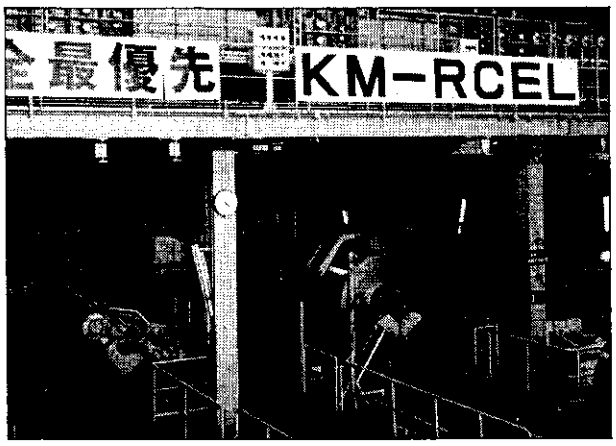


Photo 3 Entry and delivery terminal of KM-RCEL

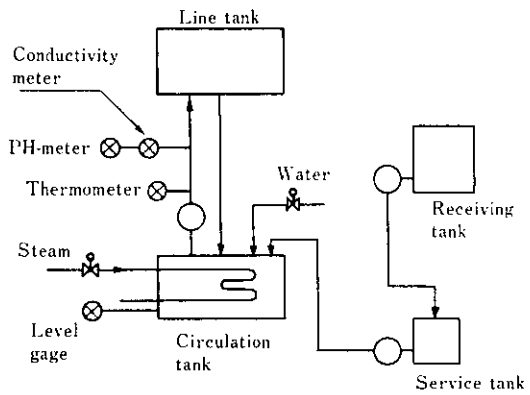


Fig. 6 Automatic solution control system

in **Fig. 6**. Most solution controls are performed smoothly by this system.

As for the chromate treatment, a system has been completed to control the chromium deposition with minimum variation through the quantitative hydrogen feed method developed independently.

4.4 Utilization of Computers

The computer system in KM-RCEL, as shown in **Fig. 7**, is effectively utilized in various phases involving production control, quality control and operation control.

Main functions of computers are described below.

(1) On-line computer
For the real-time production control.

(2) Process computer
Collection and transfer of operation and inspection data, preset controls (setting of operational and equipment conditions), anode profile control and display.

(3) Operation control DDC
Line operation main control (speed, tension, etc.), plating current control, changing of coating thickness, entry/delivery section automatic operation control, and chemical treatment automatic switching system.

(4) General instrumentation DDC
Automatic control of temperature, concentration and level of solutions, solution replenishing system, and CRT operation.

These functions are in satisfactory performance ensuring extensive labor saving and rationalization in respect of the equipment automation; collection and management of operational and quality data.

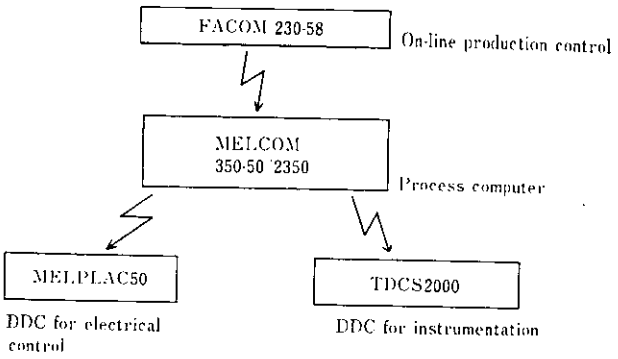


Fig. 7 Computer control system

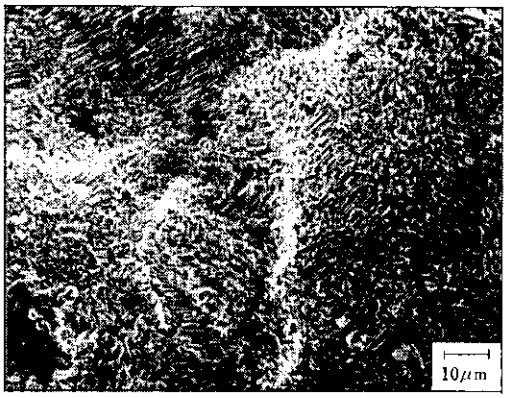
5 Quality of KM-RCEL Products

5.1 Quality of Plated Steel Sheets

5.1.1 Both-side galvanized sheets

(1) Appearance, color tone and luster
Mainly the chloride solution consists of $ZnCl_2$ with chlorides such as KCl, NH_4Cl and NaCl, and pH butters.
The crystal deposited in these chloride solutions has its shape and orientation different from that in sulfate solution[12].
When the high current density plating is performed in the chloride solution, relatively smooth and large grains of close-packed hexagonal crystal are formed, as shown in **Photo 4**. Meanwhile, plating in sulphate solution produces rough-surfaced fine crystals.
In KM-RCEL with chloride solution, the higher the current density is, the more the luster is improved, as shown in **Fig. 8**. The appearance of the plated sheet exceeds that of the conventional sulphate solution in beauty, luster gloss, and whiteness.

(a) KM-RCEL product



(b) Conventional product

Photo 4 SEM photographs of zinc deposits

(2) Profile of zinc coating weight
Figure 9 shows the profile of zinc coating weight on both side plated sheet. As stated above, both-side

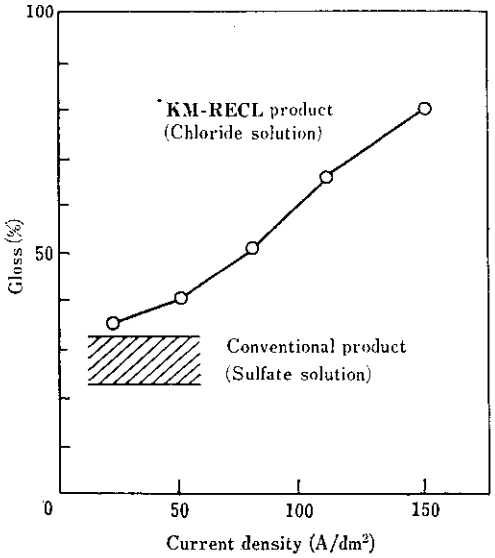


Fig. 8 Effect of plating current density on the gloss of zinc coated surface

plating in KM-RCEL gives little edge overcoat, ensuring uniform coating weight in the transverse direction and good coiling shape.

(3) Plating adhesion
Dense and uniform deposit is obtained in a wide range of current density. Therefore, the tape peeling test after 180° bending shows no peeling of coating, proving good plating adhesion.

(4) Corrosion resistance
The corrosion resistance of plated sheet without chemical treatment, as examined in the salt spray test, improves in proportion to coating weight, presenting corrosion resistance as good as sheet plated in sulfate solution.

5.1.2 One-side galvanized sheet

(1) Zinc throw-around to uncoated surface
The profile of zinc coating weight in one-side plated sheet produced by KM-RCEL is shown in **Fig. 10**. The zinc throw-around to the uncoated

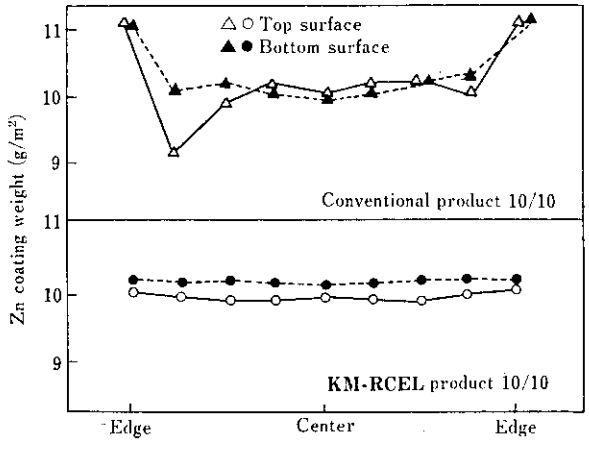


Fig. 9 Zinc coating weight profile of both-side electrogalvanized strip

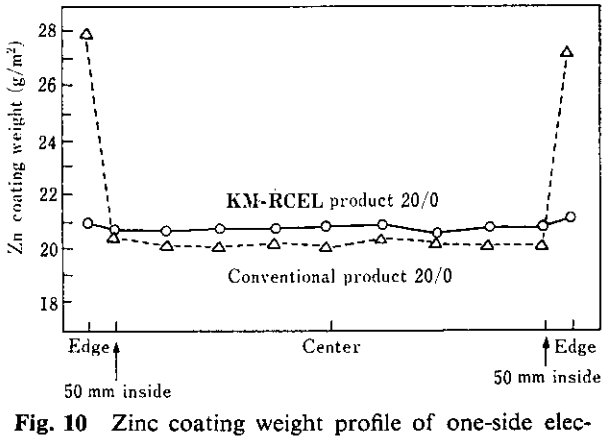
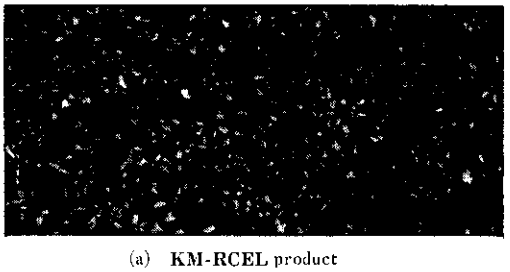
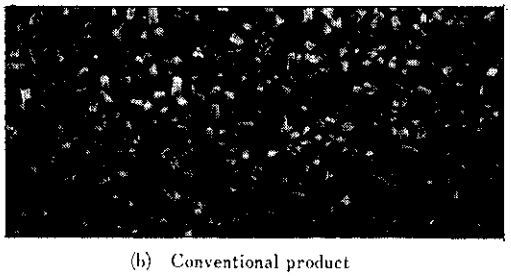


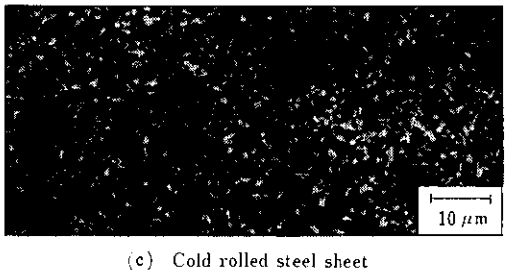
Fig. 10 Zinc coating weight profile of one-side electrogalvanized strip



(a) KM-RCEL product
P ratio : 0.93



(b) Conventional product
P ratio : 0.92



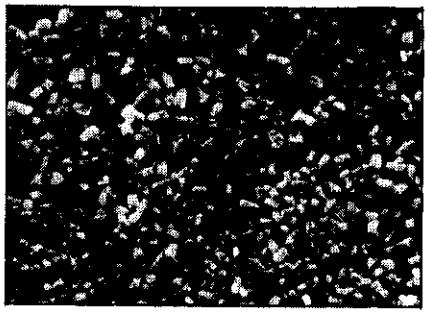
(c) Cold rolled steel sheet
P ratio : 0.92

Photo 5 SEM photographs of zinc-phosphate coatings on uncoated surface (Bonderite #3004M 50 g/l, 48–52°C, dipped)

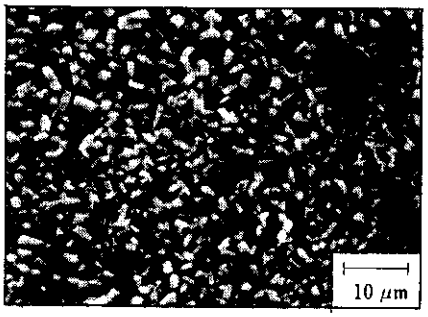
surface is shown in **Fig. 5**. The zinc deposition in the transverse direction is uniform as in case of both-side plated sheet. The throw-around of zinc to the uncoated surface, which was unavoidable in the conventional methods, is suppressed completely at the strip edges and central portions. This is extremely favorable in producing one-side plated sheet for automobiles.

(2) Phosphatability and paintability of uncoated surface

The one-side plated sheets are usually shipped after being oiled but without chemical treatment. Cleaning, phosphate treatment and electro-deposition of paint are performed by users. In order to improve the corrosion resistance of the car body, phosphatability of the steel sheet is a vital subject. The phosphate film crystals and P/(P + H) ratio[13,14] for the uncoated surface of one-side plated sheet produced by KM-RCEL are shown in **Photos 5** and **6**, respectively. After dipping or spraying treatment, crystals on the uncoated surface are as good as those on the cold rolled sheet with respect to density and P/(P + H) ratio. The coating adhesion and corrosion resistance of uncoated surface after electro-deposition and three coats (E.D. + surfacer + top coat) are as good as those of the cold rolled sheet.

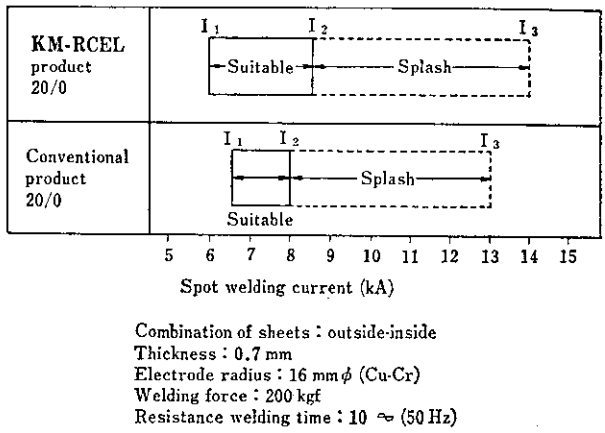


(a) KM-RCEL product
P ratio : 0.70



(b) Cold-rolled steel sheet
P ratio : 0.71

Photo 6 SEM photographs of zinc-phosphate coatings on uncoated surface (Bonderite #3128 45 g/l, 48–52°C, sprayed)



Combination of sheets : outside-inside
Thickness : 0.7 mm
Electrode radius : 16 mmϕ (Cu-Cr)
Welding force : 200 kgf
Resistance welding time : 10 ≈ (50 Hz)

Fig. 11 Single spot welding current range for one-side electrogalvanized strip

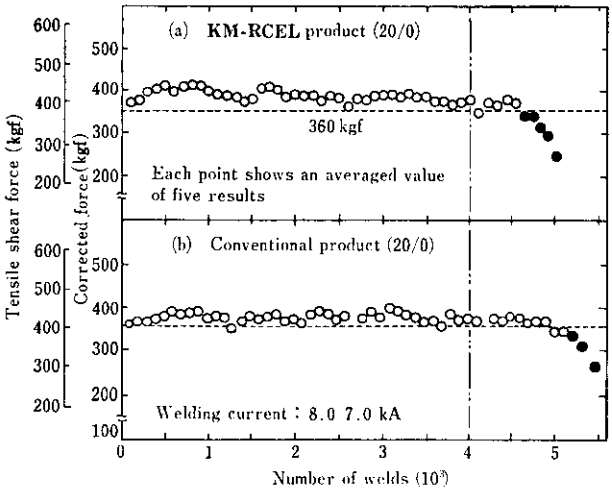


Fig. 12 Change of tensile shear force of welded portion in relation to the number of spot welds

The zinc-coated surface of one-side plated sheets also presents good phosphatability for zinc phosphate coating.

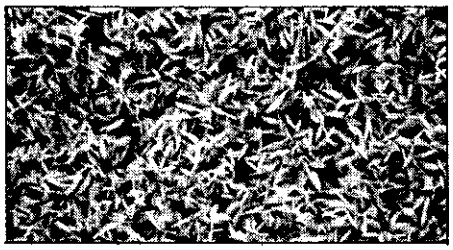
(3) Weldability

The optimum welding current range and the spot weldability of one-side plated sheets are shown in **Figs. 11** and **12**, respectively.

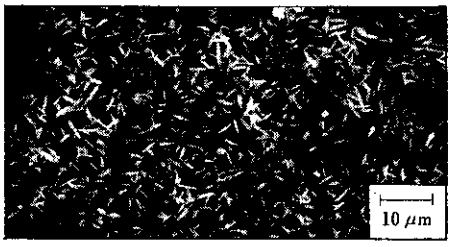
The one-side plated sheets produced by KM-RCEL present excellent quality equivalent to the conventional one-side plated sheets.

5.2 Quality of Products with Chemical Treatment

KM-RCEL permits phosphate treatment, chromate treatment and special chromate treatment in order to meet various applications.



(a) KM-RCEL product



(b) Conventional product

Photo 7 SEM photographs of zinc-phosphate coatings on zinc coated surface (Bonderite #3312 45 g/l, 62–65°C, dipped)

(1) Phosphate treatment
As preliminary to coating, the phosphate treatment aims at improving corrosion resistance and coating adhesion that are achieved by appropriate crystalline conditions and deposition amount. To this end, the composition of solution is regulated automatically, with treatment time controlled depending upon the line speed. It is required to select type of solution and treatment conditions suited for the highly reactive galvanized surface, so as to form phosphate coating of excellent whiteness. As shown in **Photo 7**, the phosphate coating crystals are of dense and homogeneous acicular structure. The characteristics of phosphate coating, such as primary corrosion protection in uncoated state (resistance to white rust in the humidity test), as well as coating adhesion, secondary corrosion resistance and chemical resistance after painting (Amilac No. 3 of Kansai Paint Co., Ltd., 25 μm), are equal to or better than those of sheets coated in the conventional processes.

(2) Chromate treatment
Three modes of chromate treatment are available: thin, normal and thick, depending upon requirements for corrosion resistance and paintability. The variation in appearance and color tone can be minimized through the appropriate selection of chromate treatment solution and treating conditions, and the control of chromium deposition by the hydrogen quantitative feeding method.

(a) Thin chromate treatment
Colorless film with a smaller amount of chromium deposition is obtained as painting base or base for laminate resin coating. The product is characterized by high luster gloss and whiteness, as well as beautiful appearance.

(b) Regular chromate treatment
For applications requiring ordinary corrosion resistance, the regular chromate treatment is suited.
The product has light-yellow luster.

(c) Thick chromate treatment
For applications requiring high corrosion resistance, the thick chromate treatment with a larger amount of chromium deposition is suited.
The product marks 72 hours or more before the generation of white rust in the salt spray test.

(3) Special chromate treatment
On the surface of strip subjected to any of three chromate treatments described above, special resin is applied and dried to provide dual-layer structure. The product is characterized by markedly improved corrosion resistance with or without further painting, and excellent antifingerprint properties.

6 Conclusions

In the foregoing chapters a new electrogalvanizing line, KM-RCEL, has been outlined as the world's first one-side/both-side plating line based on the CAROSEL system, with emphasis on its equipment and product quality.

A number of problems encountered at an early stage of both-side plating operation of KM-RCEL came to be solved through some research and improvements of our own, followed by a successful manufacture of high quality products. The operation of its one-side plating has also been successful in making products perfectly free from zinc throw-around. A chemical treatment technology for all-chloride bath plating has newly been developed into its practical stage. In summary, therefore, all the expected functions have fully been realized in general, and KM-RCEL has achieved smooth start-up and stable production in a relatively short period of time.

The authors are making continuing efforts to improve KM-RCEL through the application of innovative technologies now under research and development stage, in order to supply customers with a series of new products that will meet their ever sophisticating specifications.

The authors express their sincere gratitude to U.S. Steel Corp., USS Engineers and Consultants Inc., and many manufacturers and participants for their valuable cooperation in building and starting-up KM-RCEL.

References

1) D. T. Carter: *Iron and Steel Engineer*, **48**(1971)10, p. 54
2) British Steel Corp.: *Sheet metal Industries*, **52**(1975) 6, p. 304
3) R. F. Higgs, M. E. Komp and E. J. Oles: 75th SAE Congress & Exposition, p. 800 442, SAE Detroit(USA) Feb. (1980)
4) H. Nakanishi: Ishikawajima-Harima Engineering Review, **9**(1969)4, p. 129
5) M. Koda: *Sangyo-kikai*, (1977)326, p. 61
6) J. Oka: *Jitsumu Hyomen Gijutsu*, **78**(1978)10, p. 462
7) S. Fukuda, Y. Okubo: *Nippon Kokan Technical Report*, (1980)87, p. 43
8) K. Iwanuma, A. Matsuda: Japan Patent Laid Open Application No. 142, 891-'81
9) A. Matsuda, Y. Hirooka: Japan Patent Laid Open Application No. 142, 893-'81
10) A. Matsuda, S. Harada: Japan Patent Laid Open Application No. 43, 994-'81
11) A. Matsuda: Japan Patent Laid Open Application No. 89, 496-'82
12) Yamashita: *Journal of Applied Electrochemistry*, **9**(1979), p. 603
13) R. Kojima, H. Okita: *Tetsu-to-Haganz*, **66**(1980)7, p. 924
14) S. Naito, M. Yoneno: *The Journal of the Metal Finishing Society of Japan*, **33**(1982)7, p. 345