KAWASAKI STEEL TECHNICAL REPORT
No.20 (June 1989)
Information Systems

Development of High Image Clarity Steel Sheet LASERMIRROR

Kusuo Furukawa, Kozo Tsunoyama, Makoto Imanaka, Akira Kishida, Yasuhiro Yamada, Hiroshi Tsunekawa

Synopsis :
Controlling surface roughness of cold-rolled steel sheets as well as the paint coating technique itself is quite important in obtaining high image clarity of car outer panels. Surface roughness of cold-rolled steel sheets is usually produced by temper rolling using roughened dull rolls which is conducted by the shot-blasting or electrodischarge texturing technique. It is however, found that roughness patterns by these methods are substantially random and leaves behind waviness which deteriorates image clarity even after paint coating. By the application of laser textured roll which consists of numerous micro-craters formed by chopped laser beams, distinctness of image is much improved through elimination of waviness and providing a flat area on the steel surface. Based on this understanding, high image-clarity cold-rolled steel sheet LASERMIRROR has been developed and already applied to many passenger car outer panels.

The body can be viewed from the next page.

Development of High Image Clarity Steel Sheet LASERMIRROR*


Kusuo Furukawa
General Manager, Cold Rolling Dept., Mizushima Works


Kozo Tsunoyama
Dr. Engi., General Manager, Light Flat-Rolled Products Research Dept., I & S Research Labs.


Makoto Imanaka
Senior Researcher, Sheet Lab., Light Flat-Rolled Products Research Dept., I & S Research Labs.


Akira Kishida
Staff Assistant General Manager, Cold Rolling Technology Sec., Cold Rolling Dept., Chiba Works


Yasuhiro Yamada
Assistant Manager, Cold Rolling Sec. I, Cold Rolling Dept., Chiba Works


Hiroshi Tsunekawa
Staff Assistant Manager, Sheet Control Sec., Technical Control Dept., Chiba Works

Synopsis:

Controlling surface roughness of cold-rolled steel sheets as well as the paint coating technique itself is quite important in obtaining high image clarity of car outer panels. Surface roughness of cold-rolled steel sheets is usually produced by temper rolling using roughened dull rolls which is conducted by the shot-blasting or electrodischarge texturing technique. It is, however, found that roughness patterns by these methods are substantially random and leaves behind waviness which deteriorates image clarity even after paint coating. By the application of laser textured roll which consists of numerous micro-craters formed by chopped laser beams, distinctness of image is much improved through elimination of waviness and providing a flat area on the steel surface.

*Based on this understanding, high image-clarity cold-rolled steel sheet **LASERMIRROR** has been developed and already applied to many passenger car outer panels.*

1 Introduction

In recent years, good car body surface finish after painting has become an important quality control item, affecting the customer's perception of the car's overall quality.

The appearance of the painted surface can be improved by using better painting techniques, but the surface roughness of the steel sheet, which is the base for the painted surface, also affects surface quality after painting. Studies on this subject can be found in literature[1,2], inferring that it is difficult to balance the surface quality required for painting with degree of roughness needed to ensure easy handling and galling resistance[3] during press forming, which are the essential aims of dull surface finishing of cold-rolled steel sheet.

This is because the main control item for surface roughness has to date been average roughness. Characteristics of the actual surface roughness of steel sheets, however, include not only average roughness but other factors, and it is necessary to determine and control the factors which bear a true correlation to desired surface properties such as image clarity and press formability. This was impossible with the conventional control of surface roughness based on average roughness.

To ensure the mutual compatibility of press formability and image clarity, it is necessary to distinguish between the components of steel surface roughness detrimental to surface quality after painting and those beneficial for other properties such as galling resistance property, and to eliminate only the detrimental roughness components. The laser dull texturing technique[4] recently put into practical use makes possible finer control of surface roughness than previously, so that it is now possible to control even the roughness profile. This

* Originally published in *Kawasaki Steel Giho*, **20**(1988)3, pp. 203-209

technique was applied to the control of steel sheet roughness in consideration of the surface quality after painting, resulting in the development of high image clarity steel sheet **LASERMIRROR**.

This report gives an outline of the relationship between surface roughness and the image clarity of steel sheet, as well as techniques for controlling surface roughness developed on the basis of this relationship.

2 Image Clarity of Painted Surface

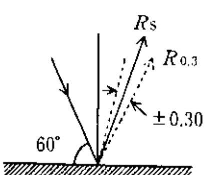
Among evaluation items for the painted surface, special importance is attached to excellent gloss with minimal irregularity of reflection from the painted surface, along with neatness of external appearance, i.e., high sharpness of reflection. In general terms, gloss and sharpness of reflection are collectively termed image clarity.

Image clarity is a characteristic which directly influences the appearance of the painted surface of a passenger car, and is evaluated most critically by visual inspection. Various image clarity measurement devices are available for the quantitative evaluation of image clarity by methods other than visual inspection. Values obtained with the DORIGON meter (manufactured by Hunter Associates Laboratory, U.S.A.), i.e., DOI (distinctness of image) values, were used in this paper. As shown in **Fig. 1**, a ray of light is projected against the sample S at an incident angle of 30°. The DOI value is expressed by the intensity of regular reflection R and the intensity of irregular reflection $R_{0.3}$ at an angle of $\pm 0.3°$ to this regular reflection ray. The higher the DOI value, the better will be the image clarity of the painted surface as judged visually. DOI values of more than 95% are cosidered necessary to ensure that the painting film of a car outer panel creates an impression of high quality in customers.

3 Surface Microstructures of Cold-Rolled Sheet

3.1 Purpose of Roughening of Sheet Surface

The general manufacturing process for cold-rolled steel sheet is shown in **Fig. 2**. After cold rolling, properties such as deep drawability are imparted by annealing. Temper rolling is then conducted to prevent stretcher strains, control the shape of the strip, and roughen the steel surface to obtain a dull finish.



$$\mathrm{DOI} = \frac{R_S - R_{0.3}}{R_S} (\%)$$

R_S: Intensity of total reflection
$R_{0.3}$: Intensity of irregular reflection

Fig. 1 Definition of DOI (distinctness of image) Value

Cold rolling → Electrolytic cleaning → Annealing → Skin-pass rolling → Finishing

Fig. 2 Manufacturing process of cold rolled steel sheet

Roughness control of cold-rolled steel sheets is a necessary part of the manufacturing process for steel sheet. A certain degree of roughness is intentionally imparted to ensure ease of handling after manufacture and to improve galling resistance during press forming. When steel strip is coiled, when steel sheet is handled in an automatic processing line or when it is press formed, the contact between sheets and between the sheet and die or handling equipment is affected by surface roughness. If surface roughness is not appropriate, sticking, galling or slip may occur, posing problems.

The surface roughening of cold-rolled steel sheets by rolling with dull rolls is conducted for this reason.

3.2 Method of Dull Surface Finishing

The control of the surface roughness of cold-rolled steel sheets is conducted by temper rolling. By rolling a steel sheet using temper rolls with roughened surfaces obtained by dull texturing, the dull finish of the rolls is transferred to the steel sheet surface. Conventionally, the shot blasting method and the electrodischarge texturing method are used to roughen mill roll surfaces. Random roughness patterns are imparted by both techniques. For example, in the shot blasting method usually adopted, the roll surface is roughened by blasting with grit appropriate to the required roughness. Due to the nature of the process, it is impossible to control the roughness profile. Similarly, electrodischarge texturing involves roughening the roll surface by melting by the electrodischarge texturing in oil, and the control of the roughness profile is impossible.

In contrast, a regular roughness pattern is imparted in the laser texturing technique, making it possible to control the roughness profile.

3.3 Method of Expressing Steel Surface Roughness

Basic parameters such as average roughness (R_a) and maximum roughness (R_{max}) have generally been used as indices for expressing the surface roughness of steel sheet. However, as a result of studies on various properties closely related to the surface roughness of steel sheet, such as ease of handling, galling resistance, and image clarity, the number of roughness parameters available as more appropriate indices has increased. For this reason, one parameter is inadequate as a description of the roughness pattern, and multiple parameters must be used simultaneously.

When regular roughness exists, as on the surface of the laser textured dull steel sheet shown in **Photo 1**, it is impossible to accurately evaluate the features of the

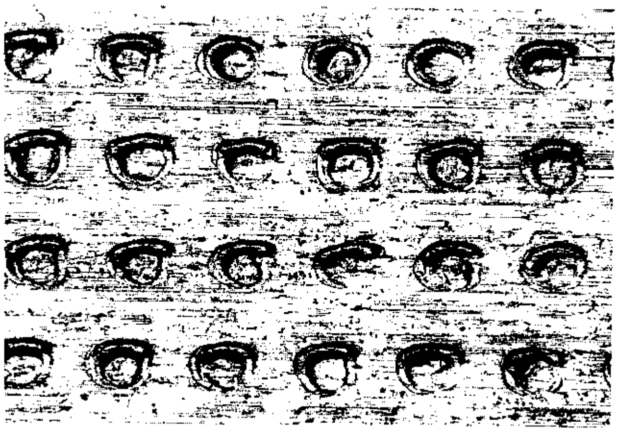
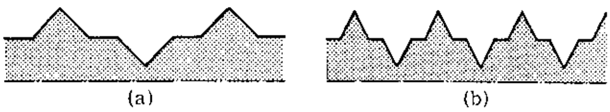


Photo 1 Surface of laser textured dull steel sheets



R_a : (a) = (b)
PPI : (a) < (b)

Fig. 4 Comparison of two different roughness profiles

roughness profile with conventional roughness measurement by one-dimensional scanning. It is necessary to conduct two-dimensional scanning and to grasp the roughness profile in a three-dimensional manner. Furthermore, when the surface sliding property, which depends on the conditions of contact between the steel sheet surface and the die, and image clarity, which depends on the reflection of light from the steel surface, are taken into consideration, it is also necessary to consider features of the roughness profile in a three-dimensional manner. Typical examples of three-dimensional roughness measurement of a laser-textured dull roll and a shot-blasted dull roll for temper rolling are shown in **Fig. 3.** In this figure, SR_a denotes the three-dimensional average roughness, and SR_Z the three-dimensional 10-point average roughness.

For example, there may be cases where the size of convex areas differs, as shown in **Fig. 4**, even when the average roughness is identical, but the two surfaces would have different surface properties. In this case, features of the roughness pattern are extracted as the difference in PPI (peaks per inch) or center-plane diameter of convex area. Moreover, the shape and spatial arrangement of convex areas are also important parameters.

When surface roughness is supposed to consist of waves of various wavelengths, the waviness component quantitatively determined by extracting roughness of long wavelengths is W_{ca}. In this study a new parameter indicating the area of flat portions as a part of surface roughness was also newly defined as $W_{2\alpha}$. This study demonstrated that these two parameters are closely related to image clarity.

4 Microstructures and Image Clarity of Steel Surface

According to the conventional view, the relationship between surface roughness and image clarity is such that image clarity increases with decreasing average roughness (R_a). The general truth of this view, as shown in **Fig. 5**, was ascertained in experiments conducted by the authors. Average roughness, however, is a value obtained by averaging roughness values of the

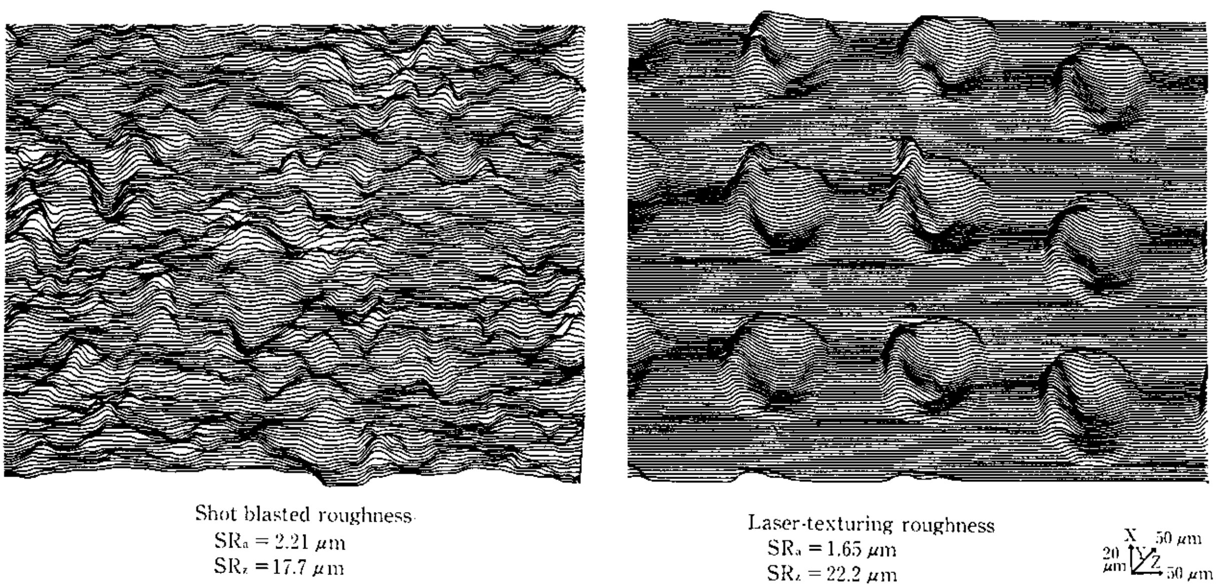


Fig. 3 Comparison of three dimensional profiles between shot-blasted roughness and laser texturing roughness of roll

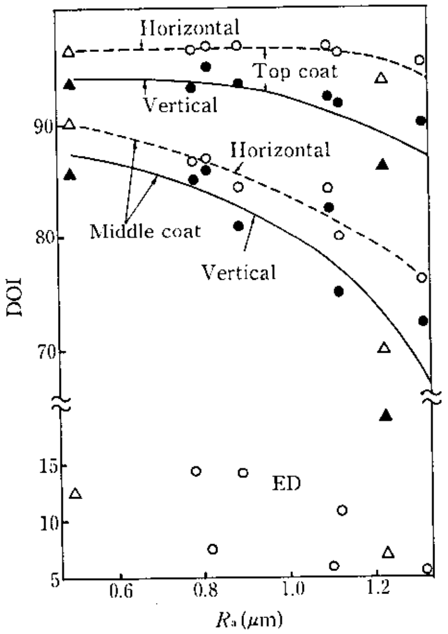


Fig. 5 Relationship between average roughness (R_a) and image clarity (DOI value)

various wavelengths composing surface roughness, and ignores the problem of which wavelengths affect image clarity after painting.

The relationship between the microstructure and the image clarity of the painted surface has been clarified fairly well through studies[5] conducted to date. In general, the roughness of the painted surface comprises wave forms with various wavelengths and amplitudes. It is known that wavelength has a great effect on surface finish quality. When image clarity is divided into three characteristics, gloss, flatness and wet look (which is intermediate between gloss and flatness), the relation to roughness wavelength is as shown in **Fig. 6**. Similarly, the surface roughness of the unpainted steel sheet is also composed of waves of various wavelengths. Whether or not waves of all wavelenths influence image clarity after the sheet is painted was, therefore, an

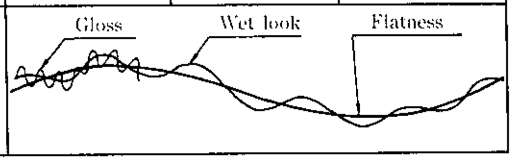
	Clarity		
	Gloss	Wet look	Flatness
Wave length	≦40 μm	40～200 μm	≧200 μm
Surface model			

Fig. 6 Wavelengths of surface roughness and image clarity

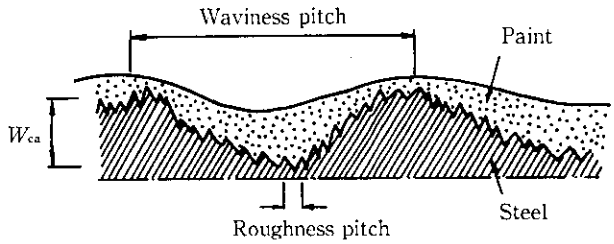


Fig. 7 Model of smoothing effect of paint layer

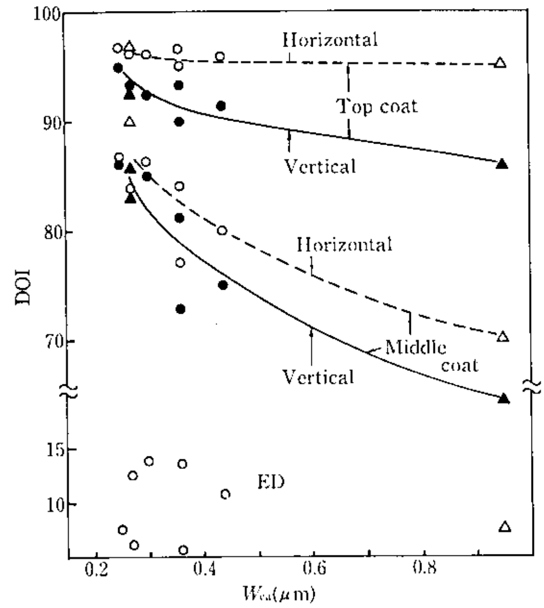


Fig. 8 Relationship between waviness (W_{ca}) and image clarity (DOI value)

important issue in the development of high image clarity steel sheet. Changes in apparent steel sheet roughness due to the painting film provide an important indication. It was revealed by a roughness analysis before and after painting that, as shown in **Fig. 7**, the short wavelength component of the roughness of the steel sheet is masked by the painting film due to the fluidity of the paint applied by spraying and the leveling effect of the paint during baking. Among several wavelength components which compose the surface roughness of the painted steel sheet, the middle wavelength component has the most significant negative effect on image clarity, and should therefore be controlled. Thus, the relationship between average roughness and image clarity shown in Fig. 5 is not an altogether accurate picture, since the improvements in image clarity are due to a reduction in the middle wavelength component. The relationship between a parameter obtained by measuring the roughness component of middle wavelength (W_{ca}) and image clarity is shown in **Fig. 8**. A strong correlation exists between the two.

Thus, while negative effects of short wavelengths are eliminated by the painting film, minimizing the middle

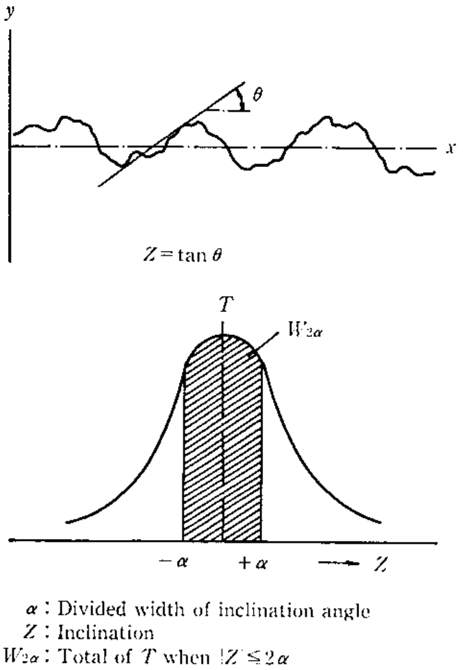


Fig. 9 Definition of flat area fraction ($W_{2\alpha}$)

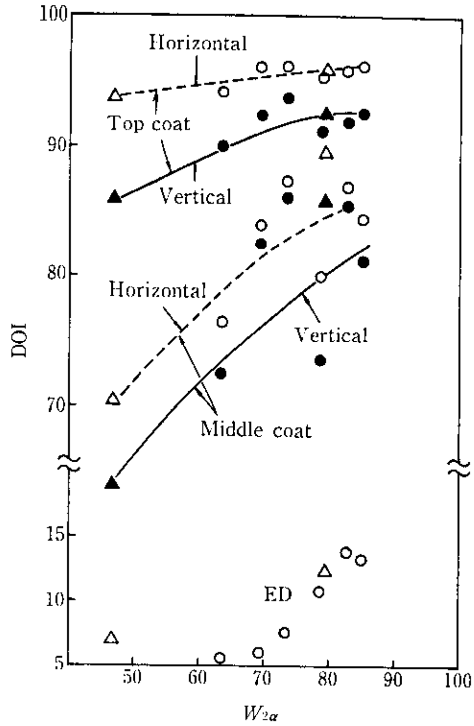


Fig. 10 Relationship between flat area fraction ($W_{2\alpha}$) and image clarity (DOI value)

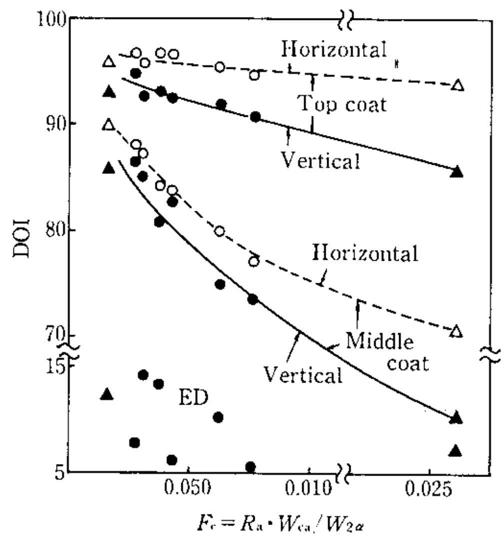


Fig. 11 Relationship between parameter F_c and image clarity

wavelength in roughness components is effective in obtaining high clarity image in steel sheets. Another effective measure is assumed to achieve high proportion of flat areas on the surface of steel sheet so that smoothness after painting will increase, improving image clarity. The flat area fraction $W_{2\alpha}$ defined in **Fig. 9** was measured and its relation to image clarity was investigated. Results of this investigation are shown in **Fig. 10**. As with the roughness component of middle wavelength, a strong correlation to image clarity was observed, and it was therefore concluded that the two parameters affect image clarity.

W_{ca}, $W_{2\alpha}$ and the average roughness were integrated and one parameter (F_c) was defined.

$$F_c = R_a W_{ca} / W_{2\alpha}$$

The relationship between this value and image clarity is shown in **Fig. 11**. A strong correlation between image clarity after painting and the F_c value was observed in various types of steel sheet.

5 Causes of Waviness in Conventional Dull Texturing Techniques and Effect of Waviness on Roughness after Painting

Roughness components of various wavelengths compose the surface roughness of the steel sheet when conventional dull texturing techniques are used. The roughness components of middle and longer wavelengths (waviness components) have an adverse effect on image clarity. In the shot blasting method, which is one of the usual dull texturing methods, random roughness given to the roll surface is transferred to the steel sheet by temper rolling. The surface roughness appears uniform at the macroscopic level, but is locally nonuniform and shows waviness. This is because the nonuniform roughening caused by variations unavoidable in the random blasting process become conspicuous at the micro level.

Results of the reproduction of this condition by computer simulation are shown in **Fig. 12**. This simulation assumed grit of different sizes equivalent to actual grain

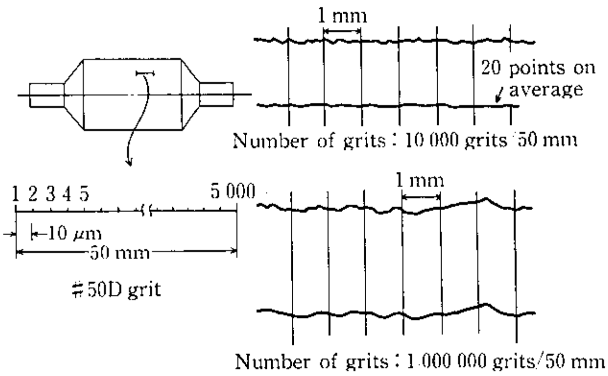


Fig. 12 Computer simulation on the generation of waviness by random shot-blasting

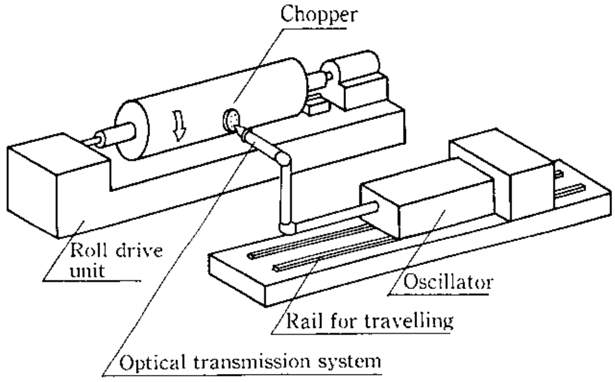


Fig. 13 Schematic illustration of the laser texturing facility

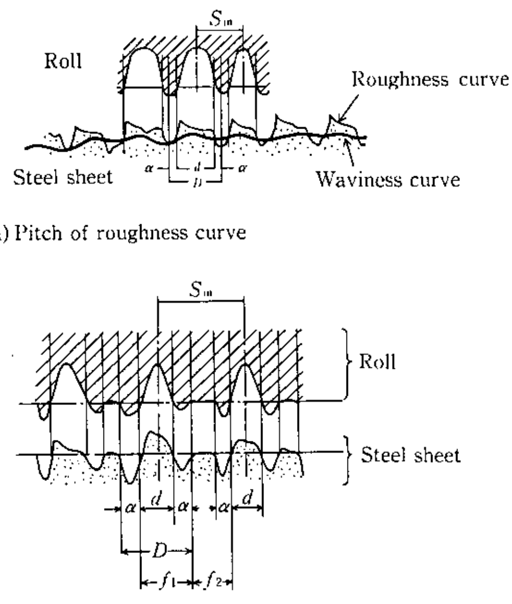
distribution are shot against the roll surface in a random manner (as determined using a table of random numbers). The roll was assumed to be worked with a damage factor corresponding to the grit size. The larger the number of the projected grit particles, i.e., the longer the shot blasting time, the higher the degree of waviness became. In other words, this simulation suggested that even if grit is shot in a completely random manner, waviness will occur due to statistical variations created by the grain size and shot position distribution of the grit.

The material characteristics of the roll itself may be an another factor. In the manufacture of rolls, dendrites structure formed during solidification after casting cause the roll surface to dendritic patterns after forging. The pitch of this pattern is several hundreds of μ m. A hardness difference occurs along the lines of this pattern, and reveals itself in differences in ductility during plastic deformation, including shot blasting, causing waviness of several hundreds of μ m. It may be concluded that waviness occurs when shot-blasted rolls are used due to these two phenomena. The generation of the waviness component is inherent in the principle of dull texturing mechanics, and cannot be eliminated.

The control of the flat area fraction, which is effective in improving image clarity, is not possible in the random roughening processes, and the bright roll surface before shot dull texturing is lost after dull texturing. Roughness components of the medium and longer wavelengths thus cannot be smoothed by painting. They remain as roughness of the painted surface and have an adverse effect on image clarity after painting.

6 Laser Dull Texturing Process

In the laser dull texturing process, unlike conventional dull texturing processes, controlled regular roughness is imparted to the roll surface. In this respect, laser dull texturing differs fundamentally from shot dull texturing, which is a random process. A laser dull texturing machine is shown schematically in **Fig. 13**. A CO_2 laser (infrared laser) is used for dull texturing, and laser beams are focused on the rotating roll surface through a lens after being converted into pulse beams by a chopper. The area on the roll surface on which the beams are focused is heated instantaneously and melts to form pools. The form of the molten pools is concave due to the pressure of an assist gas (oxygen) blown diagonally to the laser beams. Pool formation time is as short as several milliseconds. The molten pools are rapidly cooled by the base material, forming microcraters with



$$f_1 = D - \alpha = D - \left(\frac{D-d}{2}\right) = \frac{D+d}{2} \fallingdotseq D$$

$$f_2 = S_m - (d+\alpha) = S_m - \left(d + \frac{D-d}{2}\right)$$

$$= S_m - \frac{D+d}{2} \fallingdotseq S_m - D$$

Fig. 14 Waviness pitch control by laser texturing dull process surrounding flanges on the roll surface (Photo 1).

In laser dull texturing, the roll surface shows roughness with a large number of these microcraters. Craters of any size and at any pitch can be regularly arranged on the roll surface by controlling the rpm of the roll, chopping frequency, and laser output power. As a result, roughness (R_a, R_z), PPI, and waviness pitch can be completely controlled in laser dull texturing. As shown in **Fig. 14**, the roughness pitch of the laser dull textured surface is determined by the crater diameter (D) and crater intervals (S_m). In principle, this is the only roughness pitch present on the roll surface. This means that if the laser dull texturing technique is employed, it is possible to design and control the surface roughness profile of a steel sheet so as to completely eliminate wavelength components detrimental to image clarity after painting.

7 Steel Sheet LASERMIRROR

A high image clarity steel sheet called LASERMIRROR was developed by applying the laser dull texturing technique. **Figure 15** shows typical results of three-dimensional roughness measurement of conventional steel sheet rolled with shot-blasted dull roll and the new steel sheet LASERMIRROR, together with three-dimensional waviness curves (cut-off values: high 0.8 mm, low 8 mm). In the steel sheet rolled with shot-blasted dull rolls, the roughness curve is random and the waviness curve can be clearly observed. In contrast, waviness is substantially eliminated in LASERMIRROR. Wavelength components of the steel surface roughness were investigated by a frequency analysis of results of roughness measurements of similar samples. Results of this analysis are shown in **Fig. 16**. The proportion of medium wavelength components considered detrimental to image clarity is lower than in the conventional steel sheet rolled with shot-blasted dull textured rolls. Painting was conducted and the image clarity of the painted surfaces was compared in terms of DOI values.

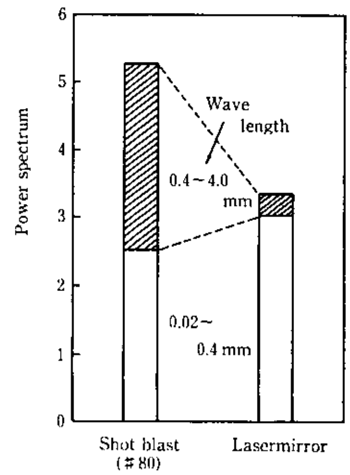


Fig. 16 Frequency components in surface roughness of LASERMIRROR and shot-blasted dull steel sheets

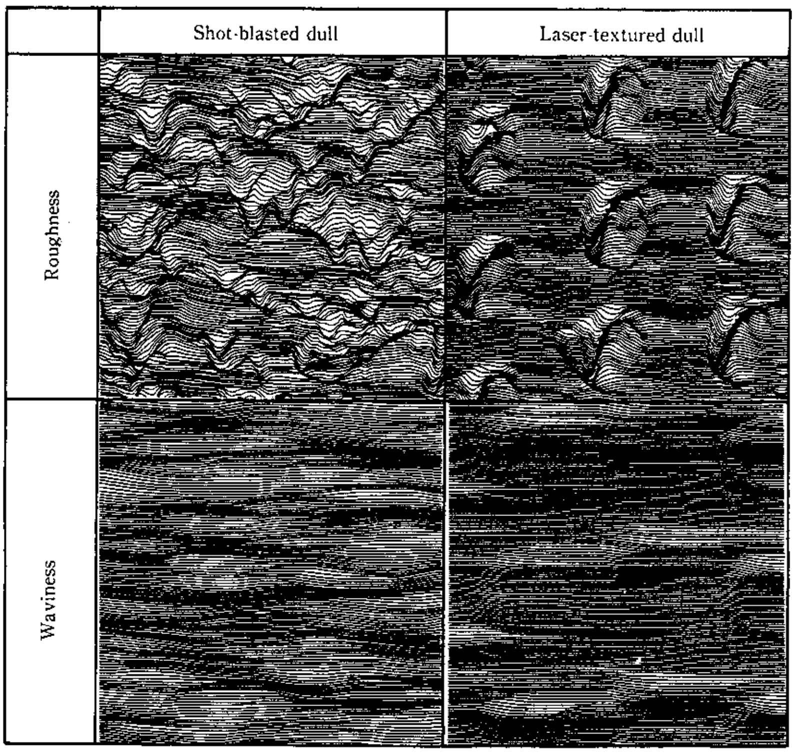


Fig. 15 Three dimensional surface roughness and waviness of LASERMIRROR and shot-blasted dull steel sheets

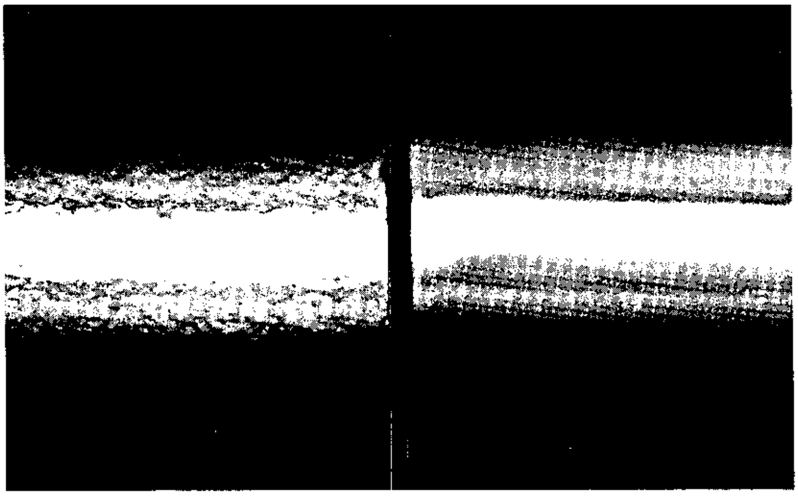


Photo 2 Comparison of reflected images on finished after coating between LASERMIRROR and shot-blasted dull steel sheets

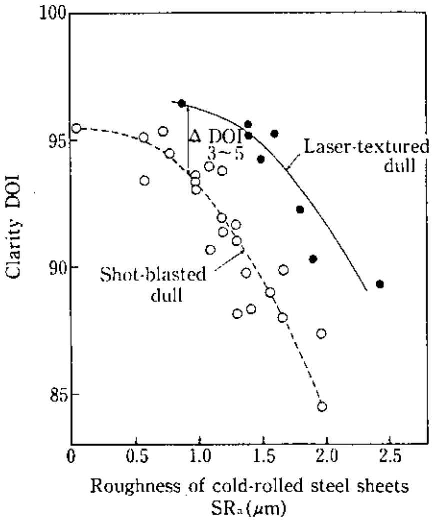


Fig. 17 Comparison of image clarity between LASERMIRROR and shot-blasted dull steel sheet surface painted 3 coat

Results of this comparison are shown in **Fig. 17**. When the results are rearranged in terms of average roughness, the DOI value of LASERMIRROR after painting is higher than that of the conventional steel sheet with shot-blasted dull texture after painting by 4 to 5 points, even at the same average roughness, because the proportion of medium wavelength components comprising the average roughness is low and flat area fraction is high in LASERMIRROR. **Photo 2** shows a comparison of the reflected images on finished surfaces after painting for LASERMIRROR and a conventional steel sheet. The projected image on paint-applied LASERMIRROR has more clear-cut contours with less distortion.

8 Conclusions

High image clarity steel sheet LASERMIRROR was developed by controlling the surface roughness of steel sheet using the laser dull texturing technique.

The following results were obtained:

(1) Among the factors determining the surface microstructures of cold-rolled steel sheets, roughness components of medium and longer wavelengths and the flat area fraction were found to have a great effect on image clarity after painting.

(2) This high image clarity steel sheet with optimum surface microstructure for the improvement of image clarity after painting was developed by applying the laser dull texturing technique, which permits control of these indices independent of roughness.

(3) Image clarity after painting (DOI value) was higher in LASERMIRROR than in conventional steel sheet by about 3 to 5 points, even at the same average roughness.

References

1) T. Furukawa and Y. Tanimoto: *Toso Kogaku (Coatings Technology)*, 19(1984) 284
2) T. G. Nilan, B. M. Perfetti, and B. J. Scialabba: SAE Tech. Paper Ser. No. 800208, (1980)
3) Japan Sheet Metal Forming Research Group: "Puresu Seikei Nan-i Handobukku (Press Forming Hand Book)" (1987), 239, [Nikkan Kogyo Shinnbun]
4) J. Crahay and A. Bragrd: Proc. 12th IDDRG Congress, (1982), 153
5) T. Fujiwara: *Journal of the Society of Automotive Engineers of Japan*, 41(1987), 601