JFE TECHNICAL REPORT
No. 24 (Mar. 2019)

Quantification of Surface Quality for Hot-Dip Zinc-Coated Steel Sheets

1. Introduction

In the production process of hot-dip zinc-coated steel sheets, the "yudare" defect (also called wrinkle-like defect), which is wavy-shaped unevenness of the steel sheet surface, occurs due to unevenness in the thickness of the zinc coating. In this work, a method for quantitatively evaluating the degree of the yudare was developed, as introduced in this article.

2. Introduction of Technology

2.1 Background

In the hot-dip zinc-coated steel sheet production process, steel strips pass through a pot containing molten zinc, and the molten zinc that adheres to the strip is adjusted to a uniform thickness by wiping the strip surface. In some cases, however, the defect called yudare may occur. The yudare defect, as shown in **Fig. 1**, is thought to occur when the molten zinc becomes uneven in the process of wiping treatment and subsequent solidification.

Conventionally, the yudare defect is evaluated by the degree by visual inspection by the operator, because no quantitative index was available. However, for product quality control and evaluation of the production process, an index that enables objective evaluation of the surface quality of the product is necessary.

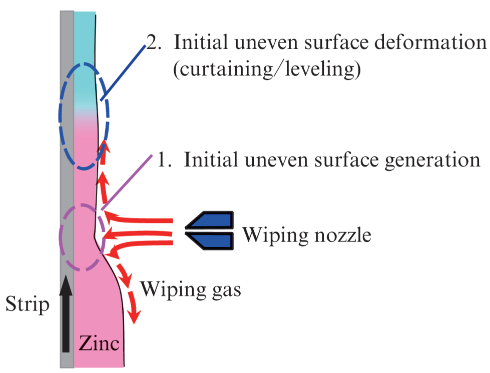

Fig. 1 Mechanism of 'yudare' defects deformation

† Originally published in *JFE GIHO* No. 41 (Feb. 2018), p. 93−94

2.2 Measurement of Unevenness of Yudare Defect

When the yudare defect exists, surface unevenness with a spacing of a few mm or more in the plane direction can be seen by visual inspection. Therefore, the unevenness of the surface was measured and then quantified by using the measured unevenness data. Measurements of unevenness were performed with a non-contact 3-D measuring instrument.

The results of measurements of yudare defects are shown in **Fig. 2**. It can be understood that unevenness with an interval of a few mm to a few 10 mm exists in the plane direction. The height of the unevenness is on the order of a few μm.

2.3 Concept of Quantification

The concept of quantification of the yudare defect will be explained in the following.

In calculating surface quality parameters, the result of extraction of the high-frequency components (for example, period λ < 0.8 mm) from a certain primary profile is called the roughness profile, and the result of extraction of the low-frequency components (for example, period $\lambda \geqq 0.8$ mm) is called the waviness profile. Arithmetic mean roughness R_a is the mean value of the absolute value of the height of the roughness profile and is known as an index of surface roughness[1].

Although, as mentioned previously, the yudare defect can be seen as unevenness with a spacing of a few mm or more in the plane direction, a comparison of the waviness profiles of light yudare and heavy yudare revealed that the spacing is different in the two types. **Figure 3** shows the waviness profiles of the parts shown by the broken lines in Fig. 2. In the case of heavy yudare, there is no difference in height, but it can

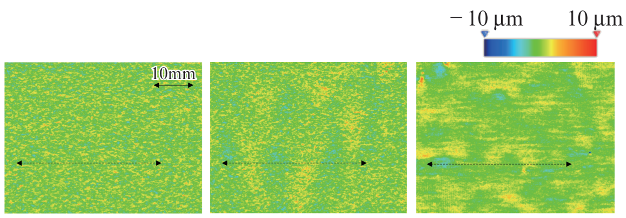

Fig. 2 Height maps of 'yudare' defects (left: no defects, center: light yudare, right: heavy yudare)

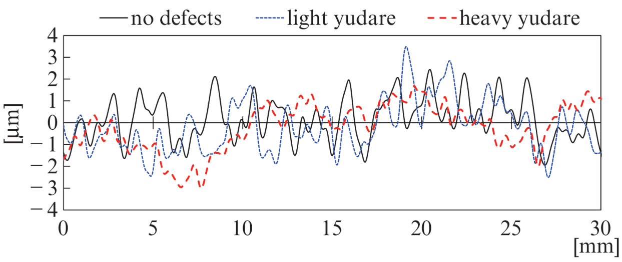

Fig. 3 Waviness profiles of 'yudare' defects

be understood that the waves exist with a larger spacing. Focusing on the size of the spacing, it was found that a defect index with a high correlation to the results of visual evaluation by inspectors can be obtained by taking the mean width of the waviness profile *WSm* (mean of the width between the starting points of waves).

Because the mean width of the waviness profile is defined for one primary profile, the mean width of multiple waviness profiles was calculated in order to quantify yudare with high accuracy. With defect-free steel sheets and sheets with light yudare defects, the mean value of the waviness profile of any primary profile has a small value. However, with steel sheets having medium or heavier yudare, it is possible to evaluate the degree of yudare by taking the mean value or the maximum value from a location where the mean value of the waviness profile has a large value, corresponding to an area where yudare exists. Comparing the mean value and the maximum value, it was found that the maximum value has a higher correlation with the evaluation by visual inspection. In evaluations by visual inspection, it is thought that the eye moves to parts that are particularly bad in comparison with other areas, and there is a tendency to judge the appearance of nonuniform and irregular parts as poor. Yudare can be quantified based on this thinking, and this is defined as index 1.

Index 1 was compared with the results when 40 samples of hot-dip zinc-coated steel sheets were prepared under different continuous hot-dip galvanizing line (CGL) manufacturing conditions and yudare scores were given to each sample by visual inspection. In the evaluation by visual inspection, the scores ranged from 0 (satisfactory) to 5 (bad) in steps of 0.5 points. **Figure 4** shows the comparison of index 1 and the scores by visual inspection. It can be understood that a high correlation with a correlation coefficient R^2=0.80 was obtained with the various samples. However, the correlation was not particularly high for samples with scores of 0 to 1.

For light yudare, as shown in Fig. 3, the spacing of the waviness profile does not differ greatly from that of yudare-free sheets. Therefore, a highly accurate evaluation is not possible by using only the above-mentioned mean width of the waviness profile. For an evaluation that distinguishes these light yudare defects from the defect-free condition, it is also necessary to extract the long-period unevenness. For this, evaluation by a height-direction parameter by applying a low-pass filter having longer-frequency cutoff value than the filter used when evaluating medium and heavier yudare is effective. **Figure 5** shows an example of the profiles after application of the low-pass filter. In particular, as a height-direction parameter, it was found that use of the maximum height of the profile has a high correlation with the results of visual inspections, and this was defined as index 2.

Figure 6 shows the relationship between index 2 and

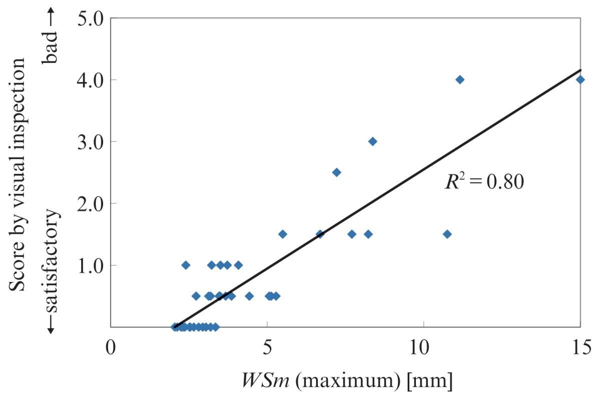

Fig. 4 Relationship between index 1 and score by visual judgment

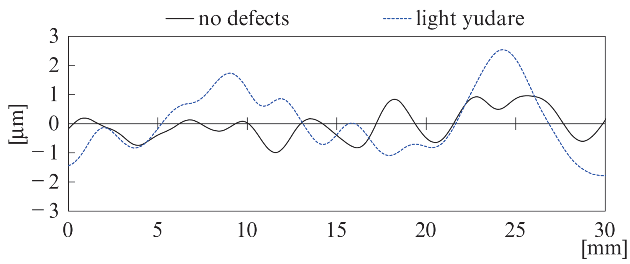

Fig. 5 Profiles after low-pass filters

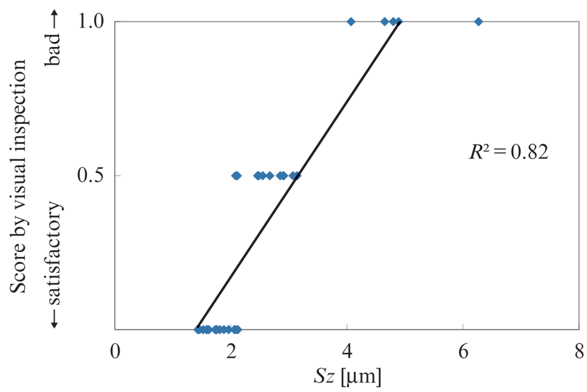

Fig. 6 Relationship between index 2 and score by visual judgment

the samples with visual inspection scores of 0 to 1. It can be understood that the maximum height of the profile *Sz*, that is, index 2, has a deeper correlation with light yudare than the maximum value of the mean width of the waviness profile *WSm*, i.e., index 1, and this is an effective index for light yudare.

2.4 Summary of Quantification Indexes

The quantification indexes are summarized in this section. As index 1, in quantification of medium to heavy yudare, multiple primary profiles are taken, and the maximum value of the mean width of the waviness profile (*WSm*) is used. As index 2, the maximum height of the profile (*Sz*) after application of a low-pass filter with a longer period cutoff value is used in order to evaluate light yudare of steel sheets that have a certain value or lower by index 1.

As evaluation indexes, this article has only introduced surface unevenness. However, accuracy can be enhanced further by using brightness in combination with the indexes described above.

3. Conclusion

Indexes for quantitative evaluation of the degree of the yudare defect were developed. By using the indexes developed in this work in product quality control and evaluation of the manufacturing process, it is possible to enhance surface appearance quality and develop new steel sheets with excellent surface quality.

References

1) ISO 13565–1 (1996).

For Further Information, Please Contact:

Instrument and Control Engineering Research Dept., Steel Res. Lab., JFE Steel
Phone: (81) 44-322-6447 Fax: (81) 44-322-6518