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Technical Report

Cutting Technologies to Improve Early Corrosion Resistance on the Cut Edge Surface of a Zn Alloy Coated Steel Sheet

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Abstract

Zn alloy coated steel sheets are used for multiple aplications because the Zn alloy coating inhibits rusting of the steel (red rust). However, because in many cases Zn alloy coated steel sheets are used after cutting, conventionally the cut edge surfaces of a Zn alloy coated steel sheet are not covered with the coating. Red rust which is on the edge surface is sometimes conspicuous, especially when the Zn alloy coated steel sheet is thick. Nippon Steel Corporation attempted to resolve this problem by developing two new cutting technologies: the KT method in which KT means inclined edge surface (Keisha-Tanmen in Japanese) and Shearing technology to prevent rust on the edge surface. These cutting technologies improved early corrosion resistance on the cut edge surface of a Zn alloy coated steel sheet. In addition, by changing the Zn alloy coating to a Zn-Al-Mg alloy coating that has a higher corrosion resistance than the Zn alloy coating, the corrosion resistance on the edge surface was also improved with these cutting technologies. The developed cutting technologies combined with the Zn-Al-Mg alloy coated steel sheet will inhibit rusting of the cut edge surfaces of the coated steel and reduce the repair frequency.

1. Introduction

Zn alloy coated steel sheets are used to enhance the corrosion resistance of steel sheets for building materials, automobiles, home electric appliances, and containers. When they are used, in many cases, they are cut to predetermined dimensions in the customers' production process by a shearing machine. However, the edge surface of a sheet cut by the conventional shearing process is scarcely covered with the Zn alloy coating. Accordingly, in the case of relatively thick Zn alloy coated steel sheets for building materials with a thickness of 3.2 mm or more in particular, red rust becomes visible on the edge surface after cutting. Therefore, a touch-up repair process by brush coating or spray coating of a corrosion inhibitor is sometimes required.[1)]

In order to improve the corrosion resistance of the edge surface with the Zn alloy coating, it is necessary for the Zn alloy coating composition to overlap the edge by enhancing the solubility of the Zn alloy as shown in **Fig. 1**.[2)] However, since the corrosion resistance of the planar section surface generally deteriorates when the solubility of the Zn alloy coating increases, it is not easy to obtain

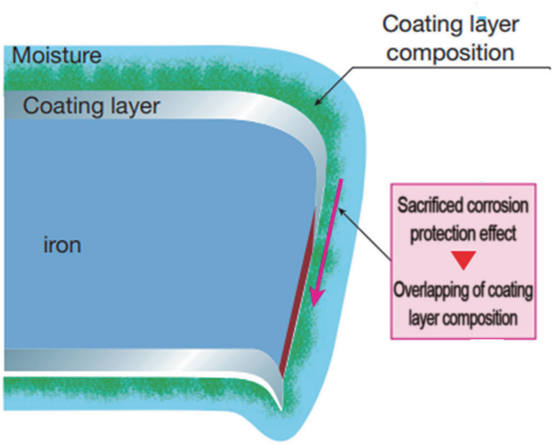

Fig. 1 Mechanism of corrosion resistance for a cut edge surface by a Zn alloy coating[2)]

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compatible corrosion resistance for both the planar section surface and the cut edge surface.[3] Additionally, in the early stage such as immediately after cutting, due to insufficient overlapping of the Zn alloy coating composition, the edge surface is susceptible to the development of red rust.

As high corrosion resistant Zn alloy coated steel sheets of the Zn-Al-Mg system, Nippon Steel Corporation has developed and produces coated steel sheets such as SuperDyma™ (SD), ZAM™, and ZEXEED™.[4–6] Furthermore, Nippon Steel has developed a post-treatment process,[7] and has improved both the planar section surface corrosion resistance and the edge surface corrosion resistance in comparison with those of the conventional Zn alloy coating. However, their provision of high corrosion resistance depends on the thickness and/or usage environment and thus is not always guaranteed.

Therefore, Nippon Steel has continued to study technologies to improve the edge surface corrosion resistance. This report introduces the following two cutting technologies that improve such resistance.

- Inclined plane edge cutting technology (hereinafter referred to as the KT method)
- Shearing technology to prevent rust on the edge surface

2. Cutting Technologies to Improve Edge Surface Corrosion Resistance

The outline of the technology, cut edge profile, Zn alloy coating coverage state, and the result of the evaluation of the cut edge surface corrosion resistance are introduced with respect to the two technologies developed.

2.1 KT method

2.1.1 Outline of the KT method

Figure 2 (a) shows the diagram of the conventional shearing process. It is reported that, in the conventional shearing process, most of the edge surface is occupied to a high degree by the fractured surface where Fe is exposed, and the rate of the area covered by the Zn alloy coating is reduced.[8] Therefore, cutting technologies were developed to improve the edge surface corrosion resistance by lowering the rate of the fracture surface, and to thus enhance the coverage rate of the Zn alloy coating on the edge surface.

Figure 2 (b) shows the diagram of the KT method developed this time. In the KT method, a triangular-convex blade is set on each of the upper and lower cutting die, and a steel sheet is cut by the compression of the dies. With this method, the following objectives were investigated.

1. During cutting, the blade presses the Zn alloy coating onto the cut edge surface, thereby increasing the coverage rate of the Zn alloy coating on the edge surface.
2. By taking advantage of the effect of hydrostatic pressure whereby a compressive force exerted onto a blank material enhances the ductility of the material, timing of the start of the fracture of a steel sheet is retarded, and the fracture surface area decreases accordingly.[9]

The dies were designed specifically to meet these objectives and to investigate whether or not the desired edge surface was obtained.

2.1.2 Observation of the edge shape and surface

(1) Condition of the KT method and observation method

For cutting, a servo press machine (ZENformer: manufactured by Hoden Seimitsu Kako Kenkyusho Co., Ltd.) was used. In this study, as **Fig. 3** shows, a die equipped with a blade having a blade tip with an angle θ of 60° and a curvature of radius R of 0.05 mm

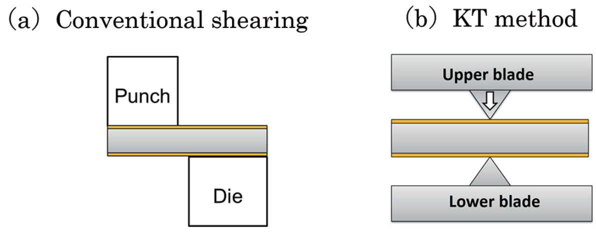


Fig. 2 Diagrams of cutting dies using

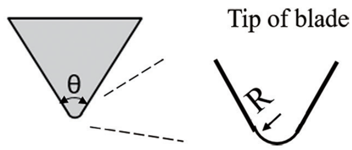


Fig. 3 Shape of the KT method's die blade

was set on the upper side and the lower side of the press machine. In the conventional shearing conducted for comparison purposes, a die which is right-angled and sharp-edged was installed respectively on the upper side and the lower side of the press machine with a clearance between the punch and die equivalent to 10% (0.32 mm) of the sheet thickness. For the test material, a hot dip galvanized steel sheet with a thickness of 3.2 mm (GI: both sides coated, approximate coating weight 900 g/m^2) was used.

After cutting with the KT method and the conventional shearing process, the frontal section and the cross section of the edge were observed by an optical microscope. The cross section was observed after embedding the sample in resin and then polishing.

(2) Result of observation of the edge shape and surface

Figures 4 (a) and (b) show respectively the result of the observation of the frontal section and the cross section of an edge cut by the conventional shearing process. The edge surface consists of a roll over, a burnished surface, and a fracture surface. Figures 4 (a) and (b) show that the burnished surface occupies as little as about 10% and the fracture surface occupies as large as about 80% of the edge surface cut by the conventional shearing process. In Fig. 4 (b), it was confirmed that roll over is covered by the Zn alloy coating. However, on the burnished surface, determination was difficult at this observation magnification.

Figures 5 (a) and (b) show respectively the result of the observation of the frontal section and the cross section of an edge cut by the KT method. The edge surface cut consists of a roll-over, an inclined plane, and a fracture surface. Based on its features of having inclined planes, this cutting process was named the KT method after its Japanese meaning of Keisha (inclined) and Tannmen (edge surface). As Fig. 5 (a) and (b) show, the inclined planes occupy an area as large as about 70%, and the fracture surface occupies an area as little as about 20% of the edge surface cut by the KT method. In Fig. 5 (b), a grey coating layer reaching almost to the center of the black steel sheet is confirmed on either of the upper and lower inclined plane.

2.1.3 Coverage state of the Zn alloy coating on the edge surface

(1) Method of measuring the coverage state of the Zn alloy coating on the edge surface

To confirm the extent of the coverage state of the Zn alloy coating on the edge surface, the state of adhesion of the Zn alloy coating

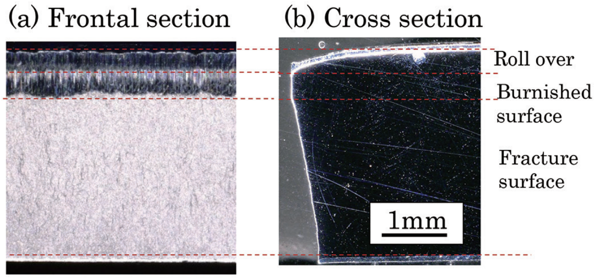


Fig. 4 Optical microscope images of conventional shearing-samples

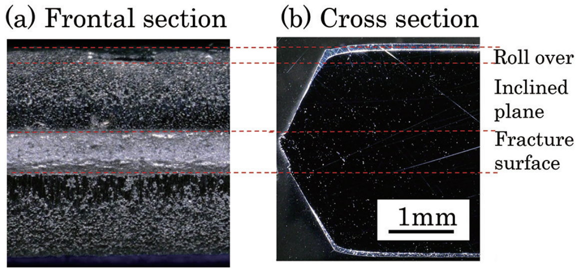


Fig. 5 Optical microscope images of KT method-samples

to the frontal section was investigated using a micro-fluorescent X-ray analyzer (μ-XRF) (ORBIS PC: manufactured by AMETEK, Inc.). The XRF was set at the following conditions: voltage at 20 kV, current at 20 μA, and beam diameter at approximately 30 $\mu m\varphi$. Since the surface of the edge cut by the KT method is not smooth, the absolute values of the detection intensity of Zn obtained at measured points cannot be compared. Then, the amount of Zn on the cut edge surface was confirmed based on the peak intensity ratio (Zn/Fe) of Kα (8.6 eV) of Zn vs. Kβ (7.06 eV) of Fe. For comparison purposes, similarly Zn on the surface of the edge cut by the conventional shearing process was confirmed. Zn within the white circle range was measured at the points from A to G in **Fig. 6**.

(2) Result of measurement of the coverage state of the Zn alloy coating on the edge surface

Figure 7 shows the result of the measurement by the μ-XRF of the Zn/Fe peak intensity ratio on the respective cut edge surfaces. In either roll over section (A) cut by the conventional shearing process or in that of (D) cut by the KT method, the Zn/Fe intensity ratio is high, and the Zn alloy coating is observed to adhere to the cut edge surface in abundance. In the KT method, as compared with the Zn/Fe intensity on the roll over (D), the intensity ratio Zn/Fe is low on the inclined plane (E) and (F). On the inclined plane near the fracture surface (F) cut by the KT method, the intensity ratio Zn/Fe is relatively low on the edge surface cut by the KT method. However, the intensity ratio Zn/Fe on the inclined plane (F) is higher than that of the edge surface cut by the conventional shearing process (B). Since the intensity ratio Zn/Fe on either (C) of the fracture surface cut by the conventional shearing process or that on (G) of the fracture surface cut by the KT method is below 0.01, we have judged that the Zn alloy coating does not exist on the fracture surface. Based on the result obtained with the μ-XRF, we have also determined that, in the KT method, the surface other than the fracture surface is covered with a thick Zn alloy coating.

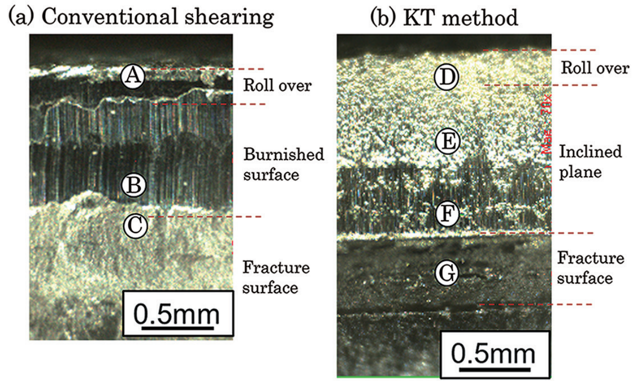


Fig. 6 Measured points of μ-XRF

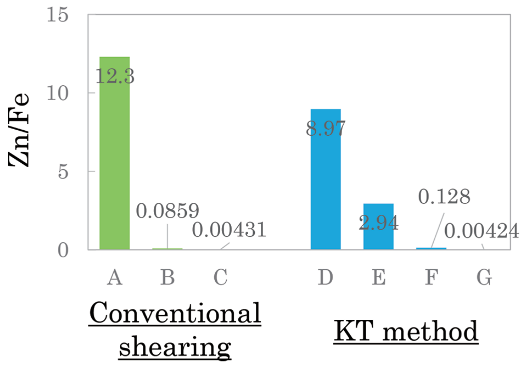


Fig. 7 Measured points of μ-XRF and Zn/Fe ratio

With the KT method, therefore, the rate of the fracture surface on the edge surface is low, and the coverage rate of the Zn alloy coating on the edge surface is high.

2.1.4 Evaluation of edge surface corrosion resistance through atmospheric exposure

(1) Test method for evaluation of edge surface corrosion resistance

The samples of the GI sheet with a thickness of 3.2 mm referred to in Paragraph 2.1.2 were cut by the KT method (die blade: θ 60°, R: 0.05 mm) and by the conventional shearing process (clearance: 0.35 mm), and their edge surface corrosion resistance was evaluated through the atmospheric exposure test.

To eliminate the influence of the corrosion of the edge surfaces other than the subject evaluation edge surface, three different edge surfaces were coated with paint. Furthermore, the samples were placed in a vertical position to the ground with their evaluation edge surface facing upward to prohibit the flow of the planar section surface Zn alloy compositions to the subject evaluation edge surface. The samples were placed at a location about 0.5 km inland from the Chiba Uchibo coast, and were exposed to atmosphere under sunlight for about one year from August 2017 to September 2018, and their edge surface corrosion resistance was evaluated. Additionally, to evaluate the deterioration of the appearance of the planar section surface due to the flow of red rust from the subject evaluation edge surface, the planar section surface was also observed. To quantitatively evaluate the edge surface corrosion resistance, as a quantification index, the red rust area ratio is defined as follows:

Red rust area ratio
= (*area of red rust on edge surface*) / (*entire area of edge surface*)
Furthermore, two samples were evaluated (N = 2), and the mean value was adopted as the red rust rate.

(2) Result of evaluation of edge surface corrosion resistance

Figure 8 shows the appearances of the edge surfaces after the atmospheric exposure. Comparing each edge surface cut by the KT method and conventional shearing process, the corrosion resistance of the former is more improved, and the former red rust rate is less than one third of the latter.

The red rust area ratio of the edge surface cut by the conventional shearing process continued to stay above 65% from the 10th day after the start of exposure until the termination of the exposure. From the time-series observation viewpoint, the red rust area ratio is about 80% after ten days from the start of exposure. As the exposure days elapse, white rust gradually grows, and covers the edge surface, and after the 200th day, the red rust area ratio drops to 65%, and is maintained at the same level until the 365th day.

The red rust area ratio of the KT method sample is about 20% from the 10th day after the start of exposure until the termination of exposure. During the exposure period, red rust is not developed on the inclined plane which is covered by the Zn alloy coating. From the time-series observation viewpoint, for 10 days after the start of exposure, red rust is developed mainly on the fracture surface, and the red rust area ratio is about 18%. At this time, red rust is not visible on the inclined plane which is covered by the Zn alloy coating. On the 50th day, a small amount of red rust is visible on the inclined plane near the fracture surface. However, it is only partial and small in terms of area, and the red rust area ratio remains unchanged at about 20%. From then until the 200th day, white rust starts to gradually cover the fracture surface in part, and the red rust area ratio lowers to about 17%. On the 365th day, the development of red rust restarts on the inclined plane near the fracture surface, and the red rust area ratio rises to about 23%.

2.1.5 Application of the KT method to high corrosion resistant Zn alloy coated steel sheet

(1) Test method for evaluation of edge surface corrosion resistance of high corrosion resistant Zn alloy coated steel sheet

In the KT method, since the edge surface is covered by the Zn alloy coating on the planar section surface, the Zn alloy coating corrosion resistance is considered to affect the rust protection performance of the edge surface. Furthermore, by optimizing the die shape pursuant to the type of Zn alloy coating and usage, further improvement in performance is expected.[10] The KT method dies were modified to an optimized shape, and used for cutting Super Dyma™ (SD: both sides coated, coating weight about 270 g/m^2) steel sheets with a thickness of 3.2 mm and with the Zn-Al-Mg alloy system. For the conventional shearing process, the same-shaped dies as those in Paragraph 2.1.2 were used. The samples were exposed under the same environment as that in Paragraph 2.1.4, and the edge surface corrosion resistance was evaluated through the atmospheric exposure to sunlight that lasted for about a year from December 2017 to January 2019.

(2) Evaluation result of edge surface corrosion resistance of high corrosion resistant Zn alloy steel sheet

Figure 9 shows the result after the exposure. In the case of SD also, the corrosion resistance of the edge surface cut by the KT

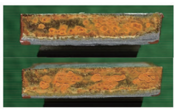
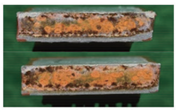
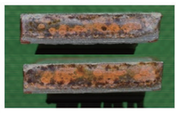
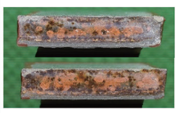
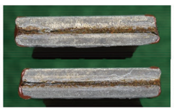
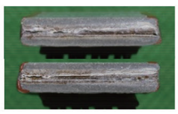
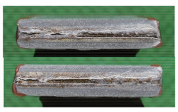
Cutting	10 days	50 days	100 days	200 days	365 days
Conventional shearing					
Red rust rate(%)	80 %	75 %	70 %	65 %	65 %
KT method					
Red rust rate(%)	18 %	20 %	17 %	17 %	23 %

Fig. 8 Appearances of the GI sample edge surface after atmospheric exposure

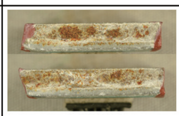
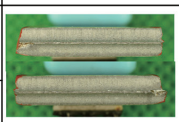
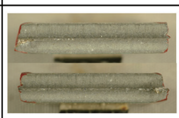
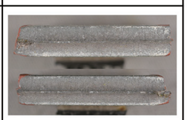
Cutting	50 days	100 days	365 days
Conventional shearing			
Red rust rate(%)	40 %	35 %	65 %
KT method			
Red rust rate(%)	3 %	3 %	3 %

Fig. 9 Appearances of the SD sample edge surface after atmospheric exposure

method is improved from that of the edge surface cut by the conventional shearing process. The red rust area ratio of the KT method sample remains at about 3% from the 50th day after the start of exposure until the termination of the exposure, and the red rust is suppressed to a level low enough to be almost unrecognizable at a glance.

Although it is difficult to conduct a simple comparison due to the difference of the corrosion test starting date between the GI sample described in Paragraph 2.1.4 and the SD sample, a comparison of the results in Figs. 8 and 9 reveals the following:

When the pair of the conventional shearing samples is compared, until the 100th day, the red rust area ratio of SD is smaller than that of the GI; however, its difference is large, and on the 365th day, this difference disappeared. On the other hand, when the pair of KT method samples is compared, on the 50th day after the start of exposure, the red rust area ratio of the SD sample is smaller than that of the GI, and even after 365 days, the difference in the red rust area ratio remains at the same level. This indicates that the combination of the KT method and the high corrosion resistant Zn alloy steel sheet is effective in improving the edge surface corrosion resistance.

Thus, it is confirmed that the edge surface corrosion resistance is improved by using a combination of high corrosion resistant Zn alloy steel sheets and the KT method.

2.2 Shearing technology to prevent rust on the edge surface

2.2.1 Outline of the technology

The concept of the shearing technology to prevent rust on the edge surface is based on the premises that: "① Die configuration is identical to those of the conventional shearing process, ② Cross sectional shape of the cut edge is equivalent to that of the edge cut by the conventional shearing process, and ③ Application to both straight line shape cutting and hole shape punching is possible", and a shearing blade was developed, which is capable of providing rust protection performance to the cut edge surface of a Zn alloy coated steel sheet.

Figure 10 (a) shows an example of the die configuration of the conventional shearing process, and (b) shows an example of the die configuration of the shearing technology to prevent rust on the edge surface. In the conventional shearing process, a punch/die having a right-angled and sharp-edged top is used as a shearing blade. On the other hand, in the shearing technology to prevent rust on the edge surface, a step with a curvature of radius of R is provided at the edge of the top of one punch/die, while the other uses the same as that of the conventional shearing process. Thus, the die arrangement of the shearing technology to prevent rust on the edge surface is the same as that of the conventional shearing process. However, part of the top shearing blade shape is different. Hereafter, the shearing blade used to prevent rust on the edge surface is termed as the stepped shearing blade, and the shearing blade used for the conventional shearing process is termed as the conventional shearing blade.

With the stepped shearing blade, the stepped section provided on the punch top exerts bending deformation on the cutting section of a Zn alloy coated steel sheet, and inclines the section. Then the R part of the step intrudes and irons the bent section, and then cuts it. The coating layer is not split by the R section of the top die edge, and as a hydrostatic pressure is produced by ironing and the fracture is delayed accordingly, the burnished surface rate is improved.

2.2.2 Simplified prediction method of the movement of coating by CAE

Since it is difficult to observe the movement of the coating layer during cutting, a simplified movement prediction method using computer aided engineering (CAE) was examined. **Figure 11** shows the result of the prediction of the movement of the coating layer during cutting with each shearing blade. MSC Marc was used for CAE, and a two-dimensional model was developed. By tracking the movement of the observation points set on the surface of the material at a distance of 20 μm, the state of movement of the coating layer during cutting was represented. In addition, the change of the thickness of the coating layer was predicted based on the extension of the set point distance. The result of CAE confirmed that with the conventional shearing blade having a sharp top edge, the coating layer is divided at the early stage of cutting, and with the stepped shearing blade with R at its top edge, the burnished surface is formed without dividing the coating layer, enhancing the coating coverage rate on the sheared edge surface.

2.2.3 Coverage state of coating on the edge surface

Figure 12 shows photographs of the section of the edge of a Zn-Al-Mg alloy coated steel sheet (ZAM™: sheet thickness 3.2 mm,

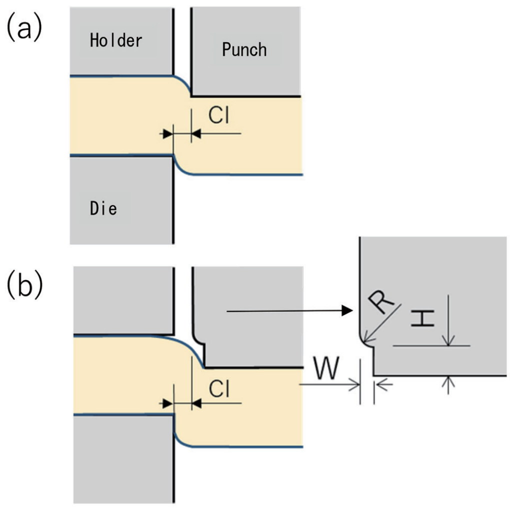


Fig. 10 Diagrams of shearing tools
(a) Conventional shearing, (b) Developed shearing

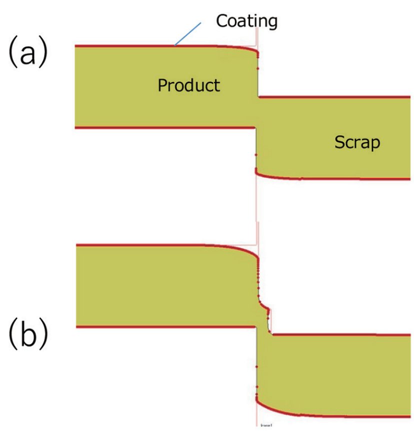


Fig. 11 Movement prediction of coating (CAE)
(a) Conventional shearing, (b) Developed shearing

both sides coated, coating weight about 275 g/m^2), cut by the stepped blade. The rate of the fracture surface where iron is exposed is reduced on the edge surface cut by the stepped blade, and the coating covering the burnished surface is confirmed. On the burnished surface near the fracture surface, since the coating layer is very thin and difficult to recognize through observation of the cross section, the coverage state of the coating composition was investigated through elementary analysis on the surface by using EPMA. **Figure 13** shows the result of comparison of the Zn distribution on the edge surface of a ZAM™ (sheet thickness 3.2 mm, both sides coated, coating weight about 275 g/m^2) cut by the stepped blade and the conventional blade. Through the analysis of the edge surface, it is confirmed that the Zn composition becomes thin on the lower part of the edge surface cut by the conventional blade, while on the other hand, the entire edge surface cut by the stepped blade is covered with rich Zn composition. Although the coating coverage rate (the rate of the width of roll-over plus burnished surface vs. sheet thickness) on the edge surface cut by the conventional blade is about 30%, the coating coverage rate on the edge surface cut by the stepped blade is about 90%. Accordingly, the rate of the fracture surface where iron of the steel sheet is exposed reduces significantly.

2.2.4 Evaluation of edge surface corrosion resistance through atmospheric exposure

(1) Test method for the evaluation of edge surface corrosion resistance

Square test samples of 40×40 mm were punched out from ZAM™ (sheet thickness 3.2 mm, both sides coated, coating weight about 275 g/m^2) with the conventional shearing process (conventional blade, Cl: 8% (0.26 mm)) and with the shearing technology to prevent rust on the edge surface (stepped blade, Cl: 2% (0.06 mm), R: 0.5 mm, W: 0.5 mm, H: 1.0 mm), and their edge surface appearances were observed throughout an atmospheric exposure test. The samples were placed in the coastal area of Sakai City, Osaka Pref. for a period from April to October in 2021. As **Fig. 14** shows, the samples were placed at an inclination angle of 35°, and their side surfaces were observed. The edge surface corrosion resistance was evaluated based on the comparison of the red rust rate described in Paragraph 2.1.4.

(2) Result of the evaluation of edge surface corrosion resistance

Figure 15 shows photographs of the appearances of the edge surfaces after the atmospheric exposure test. On the edge surface cut

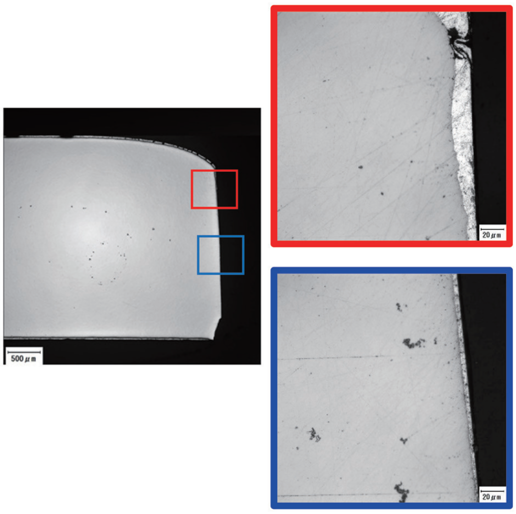


Fig. 12 Optical microscope image of edge surface rust protection shearing sample

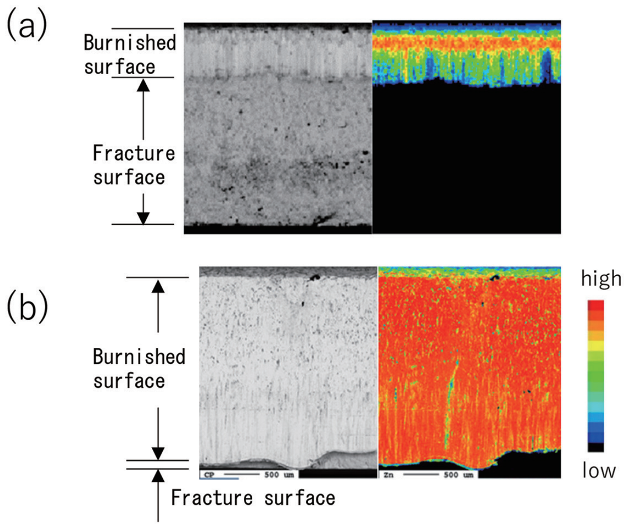


Fig. 13 Zinc distribution on shearing edge surface (EPMA)
(a) Conventional shearing, (b) Developed shearing

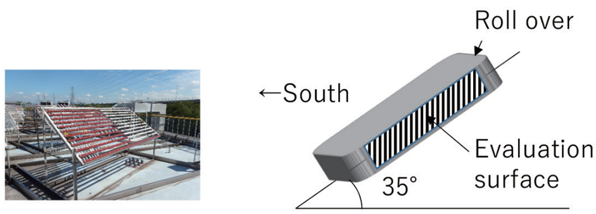


Fig. 14 Atmospheric exposure test condition

Cutting	7 days	30 days	60 days	90 days	180 days
Conventional shearing					
Red rust rate(%)	11%	67%	64%	59%	57%
Developed shearing					
Red rust rate(%)	3%	2%	4%	4%	1%

Fig. 15 Appearance of sheared edge surface after atmospheric exposure

by the conventional blade, since the rate of the fracture surface is large as described earlier, after the elapse of 30 days of atmospheric exposure, the edge surface was covered with red rust in a wide range as large as 67% in terms of the red rust area ratio. On the other hand, on the edge surface cut by the stepped blade, as the burnished surface covered by the Zn coating becomes enlarged, the red rust area ratio is 1% even after the elapse of 180 days, and rusting can be significantly suppressed.

From the above, it is confirmed that the rust protection capability of an edge surface in the early stage is improved by changing the shape of the cutting blade used for the shearing process since the edge surface is covered by the coating layer on its steel sheet surface.

3. Conclusion

This article reports two types of cutting technologies that improve the edge surface corrosion resistance, and the following findings were obtained.

- Effect of improving the edge surface corrosion resistance of either the KT method or the shearing technology to prevent rust on the edge surface was confirmed.
- Further improvement of edge surface corrosion resistance was confirmed by combining the KT method with, instead of conventional Zn coated steel sheets, the high corrosion resistant Zn alloy coated SD steel sheet manufactured by Nippon Steel. Furthermore, as a result of combining the shearing technology to prevent rust on the edge surface with ZAM™, excellent edge surface corrosion resistance was verified.
- Features of the respective technology are summarized in **Table 1** below. In the KT method, since the shape of the edge becomes different from that of the edge cut by the conventional shearing process, care must be taken when deciding the specification of processed goods. However, such care is unnecessary for the shearing technology to prevent rust on the edge surface as the shape of the edge cut by the technology is similar to that of the edge cut by the conventional shearing process. Furthermore, with the KT method, the edge surface corrosion resistance of the cut off portion of the cut material is also improved similarly to the product side edge surface. However, with the shearing technology to prevent rust on the edge surface, the edge surface corrosion resistance of the cut off steel sheet is not improved. Therefore, care must be taken with the direction of cutting. In this research and development, the respective technology was studied based only on that of a press machine. Hereafter we will continue to study whether these technologies are applicable to other cutting mechanisms. Further, these results of the evaluation of the edge surface corrosion resistance of respective cutting technologies cannot be compared unconditionally due to the differences in the type of coating and the exposure circumstances. Additionally, since the cut shape, intended use environment, cost, and so forth differ depending on customers who actually conduct the cutting operation, and on their intended use, it is necessary to select the optimal method and/or the condition best suited to the respective customers.

Although these technologies in no way guarantee the corrosion resistance, their performance has been improved in contrast with that of the conventional shearing process, and the technologies are applicable to various products. Additionally, if these technologies are applied to the materials that still require touch-up repair of the edge surface, the frequency of such touch-up repair work immediately after cutting may be reduced. With the development of these cutting technologies, further growth of the use of Zn alloy coated steel sheets is expected, and with the application of these technologies, we can contribute to society through the reduction of environmental loading and effective utilization of human resources.

Table 1 Comparison of developed cutting technologies

Compared items	KT method	Shearing technology to prevent rust on the edge surface
Similarity of edge shape with traditional method	Not similar	Similar
Availability of another cut sample	Available	Not available
Equipment required to cut	Press machine	Press machine

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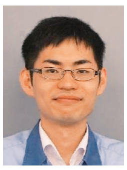

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