Investigation of Cause and Prevention Measures against Surface Defects on Thermit Welds

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In Japan, four welding processes have been generally adopted for producing continuous welded rail (CWR): flash welding (FW), gas pressure welding (GPW), enclosed arc welding (EAW), and thermit welding (TW). Thermit welding method is the most popular rail welding process in Japan. The reliability of the thermit welds is high, because the failure rate has only been about 0.004 % over the last 10 years in Japan. However, recently there have been many cases where thermit welds are judged to be defective due to surface defects. Surface defects are often observed when welding new and worn rails. Welding test results show that surface defects are caused by gas generated from the contact of luting sand with molten steel which enters gaps between the welding mold and rail surface.

Keywords: thermit weld, surface defect, blowhole, rail step, gap, luting sand

1. Introduction

In Japan, four welding processes have been generally adopted for producing continuous welded rail (CWR): flash welding (FW), gas pressure welding (GPW), enclosed arc welding (EAW), and thermit welding (TW). Figure 1 shows the current application ratio of each welding process. Thermit welds account for approximately 40 % of all welding. The reliability of thermit welds is high, because the failure rate has been only about 0.004 % over the last 10 years in Japan. Therefore, thermit welding is an indispensable welding method for track maintenance.

However, recently there have been many cases where thermit welds are judged to be defective due to surface defects, as shown in Fig. 2. Surface defects are often observed when welding new and worn rails. It is thought that surface defects are caused by gas generated from the contact of luting sand with molten steel which enters gaps between the welding mold and rail surface. However, as yet there is no clear evidence to explain this phenomenon. Clarifying the cause of surface defects and proposing preventive measures are therefore crucial for track maintenance.

This paper describes the results of examinations carried out to clarify the cause of, and suggests a series of preventive measures against surface defects.

Fig. 1 Application ratio of each welding process

Fig. 2 Surface defects found on thermit welds
2. Problem encountered when welding new and worn rails

Thermit welding is always used when replacing damaged rails, whereby the new rail is welded to the old rail. As the old rails are worn by passing trains there is a height difference between the two rails to be welded. When this difference is large, it is difficult to set the welding mold to the rails. Furthermore, depending on the location, old rails are sometimes very rusty.

Figure 3 shows the setting of the welding mold, where there is a gap between the welding mold and the rail. The height difference between the two rails to be welded is 4mm. When using a standard welding mold without any treatment, the welding mold needs to be set at the center of the welding gap so as to set the preheating burner at the center of the welding gap as shown in Fig. 3(a). However, in this setting, the bottom of the welding mold shifts from the center of the welding gap because the welding mold is leaning too heavily. This is dangerous because it could prevent proper fusion and cause molten steel to leak.

Figure 3(b) shows the welding mold where the welding mold is reshaped through grinding, which is usually used for standard welding work between new and worn rails. Although the preheating burner can be set perpendicular to the center of the welding gap with grinding treatment of the standard mold, large gaps appear at the bottom and around the jowl of the worn rails. If ramming of luting sand is performed in this case, luting sand would enter into the gap as shown in Fig. 3(c). On the other hand, if a step mold is used, the mold can be set to the rail perpendicularly and no gap appears, because the step mold is specially designed for welding when there is a 4 mm difference in rail height between the mutually welded rails (Fig. 3(d)). The step mold can be applied in the cases where rail height difference is from 2 mm to 6 mm [1].

3. Welding tests on new rails and worn rails

Most surface defects, such as blowholes, form from the gap between the mold and the rail to the center of the weld (Fig.2). This fact suggests that surface defects are caused by gas generated from contact of luting sand with molten steel, which then enters the gap between the welding mold and the rail surface. Accordingly, welding tests of new and worn rails were conducted using standard and step molds to clarify the influence of rail surface rust, and the gap between the welding mold and the rail surface, on the occurrence of surface defects.

3.1 Welding test conditions

Table 1 shows the welding test conditions. First the influence of rust on surface defect occurrence was investigated when using step molds. Subsequently, the influence of the gap between the welding mold and the rail on the occurrence of surface defects when using a ground standard mold was examined. The influence of moisture in the luting sand, and the effect of filling the gap between the welding mold and the rail with paste to prevent molten steel coming into contact with luting sand were also examined.
was about 3 mm. As mentioned above, the step mold fits completely on to the rails during welding, leaving no gap.

In the case of a ground standard mold, a 2.5 - 3.0 mm gap appears between the welding mold and the bottom of the worn rail. There are also gaps between the mold and the rail jowl as shown in Fig3(c). 20 welds were carried out in these tests. All the welds were executed in standard welding conditions (torch pressure of oxygen: 0.45 MPa, preheating time: 90 s).

### 3.2 Occurrence of defects in the test welds

Table 2 summarizes visual and ultrasonic tests carried out on the test welds. In these tests, only one weld, conducted with a 40% increase in luting sand moisture content, was observed to produce a surface defect (TPNo.N-8). Figure 4 shows the blowhole which occurred on the head side of the worn rail.

Table 2 shows in the TPNo.N-7, carried out with a 20% increase in luting sand moisture content, the internal defect in the rail head was detected by ultrasonic inspection. Accordingly, the area was ground with a disk grinder. The grinding exposed the blowhole situated near the casting fin on the jowl of the worn rail, as shown in Fig.5.

Class 1 or class 2 defects were detected in approximately 80% of all the test welds using a single probe technique applied to the rail base, as shown in Table 2. Figure 6 is an example of an image showing the flawed echo which was detected in the base area of the weld by applying the single probe technique to the rail base. The side of rail base was ground to investigate the inside of the weld. As a result, the blowhole was exposed near the casting fin generated in the bottom part of the worn rail as shown in Fig.7.

### 3.3 Occurrence of defects in the cross section of each weld

Figure 8 shows the occurrence of defects in the cross section of each weld. No blowhole was observed on the new rail side where there was no gap between the welding mold and the rail as shown in Fig.8 (a). However, some blowholes occurred in the jowl and bottom part of the worn rail side where there was a gap between the welding mold and the rail (Fig.8 (b)). Meanwhile, no blowhole was observed in the bottom part of the rail weld which was where the weld was conducted after having filled the gap at the bottom of the rail with paste (Fig.8 (c)). No blowhole was observed either on the worn rail side of the weld which was carried out applying the step mold, because there was no gap (Fig.8 (d)). This confirmed that a hollow appears on the rail surface, if paste can enter into the mold.
| TPNo. | Head part | Base part | Existence of surface defect |
|-------|-----------|-----------|----------------------------|
|       | Single probe technique | Double probe technique | Single probe technique | Double probe technique |
| S-1   | ―         | ―         | Class 1 (18 %)             | Class 2 (25 %)           | No                      |
| S-2   | Class 1   | ―         | Class 2 (21 %)             | Class 2 (25 %)           | No                      |
| S-3   | ―         | ―         | Class 2 (22 %)             | ―                        | No                      |
| S-4   | ―         | ―         | Class 2 (22 %)             | Class 2 (25 %)           | No                      |
| N-1   | ―         | ―         | Class 2 (22 %)             | ―                        | No                      |
| N-2   | ―         | ―         | Class 1 (16 %)             | ―                        | No                      |
| N-3   | ―         | ―         | Class 2 (27 %)             | ―                        | No                      |
| N-4   | ―         | ―         | Class 1 (14 %)             | ―                        | No                      |
| N-5   | ―         | ―         | Class 1 (14 %)             | ―                        | No                      |
| N-6   | ―         | ―         | Class 2 (26 %)             | ―                        | No                      |
| N-7   | Class 4   | Class 2 (32 %) | ―                       | ―                        | No                      |
| N-8   | Class 1   | ―         | Class 2 (17 %)             | ―                        | Yes                     |
| N-9   | Class 3   | Class 2 (28 %) | Class 2 (18 %) | ―                        | No                      |
| N-10  | ―         | ―         | Class 1 (19 %)             | ―                        | No                      |
| N-11  | ―         | ―         | Class 1 (16 %)             | Class 2 (40 %)           | No                      |
| N-12  | ―         | ―         | ―                          | Class 2 (27 %)           | No                      |
| N-13  | ―         | ―         | ―                          | Class 3 (50 %)           | No                      |
| N-14  | Class 2   | Class 1 (16 %) | ―                       | Class 2 (23 %)           | No                      |
| N-15  | ―         | ―         | Class 2 (25 %)             | ―                        | No                      |
| N-16  | ―         | ―         | ―                          | Class 3 (51 %)           | No                      |

— : less than Class 1

| Distance from base side of rail (mm) |
|--------------------------------------|
| 0 | 40 | 80 | 120 | 160 | 200 |
| Class 1 | Class 2 | Class 3 | Class 4 |

Worn rail

New rail

Blowhole

Casting fin

Fig. 6 An example of the flawed echo which was detected in the base area of the weld by applying the single probe technique to the rail base (TPNo. N-6)

3.4 The collar root in the area around the bottom of the rail

Figure 9 shows the collar root in the area around the bottom of the rail. No casting fin was observed around the base of the rail at the bottom of the weld executed with a step mold, and the root shape of the weld appears to be sound, c.f. Fig. 9 (a). A 5 mm thick casting fin appeared throughout the bottom of the weld on the rail, when the ground type standard mold was used, because molten steel
entered the gap between the welding mold and the worn rail (Fig. 9 (b)). No casting fin was observed at the bottom of the weld on the rail when welded after filling the gap at the rail bottom with the paste, as shown in Fig. 9 (c).

**Fig. 8 Blowholes which were observed in the cross-section**

4. Performance tests on welds which have blowholes in the base area of the rail

Ultrasonic tests and four-point bending fatigue tests were performed on the welds removed from in-service railway lines due blowholes on the upper side of the weld collar of the rail base, as shown in Fig. 2 (b), to evaluate their bending fatigue strength.

4.1 Ultrasonic tests

Although it is impossible to detect blowholes in the upper part of the rail base collar using a double probe technique on the rail base side, because they are outside the detectable area, it is possible to detect them as Class 1 or 2 defects using the single probe technique to the rail base. If the non-detectable area is removed by grinding the collar around the rail base, blowholes can be detected as class 1 or class 2 defects using the double probe technique.

4.2 Bending fatigue test

A four-point bending fatigue test was performed in the HU position to generate tensile stress in the rail base area of the weld, in which the blowhole occurred at the upper part of the rail base collar. The weld was supported with an outer span of 1.3 m (inner span: 0.15 m), and pulsating stresses of a minimum of 30 N/mm², while a stress range of 180 N/mm² was applied up to two million times. It is considered that the weld, which demonstrated a fatigue strength of 180 N/mm² (stress range), would not fail on a revenue line [2]. Table 3 shows the results of the ultrasonic tests and bending fatigue tests.

The welds, which were found to have class 1 defects, detected through the double probe technique (TPNo.F1-
F3), did not break after two million stress applications. Furthermore, it is considered that the fatigue cracks due to the blowholes did not occur, because the echo height of ultrasonic tests did not change before and after the bending fatigue tests. Welds were found to have class 2 defects after applying the double probe technique (TPNo.F4), however, broke after 350,000 stress applications.

These results suggest that the soundness of the base area of the thermit weld can be evaluated using the double probe technique in ultrasonic tests, regardless of the existence of surface defects. Consequently, welds with defects smaller than class 1 defects should be evaluated as successful.

### Table 3 Results of ultrasonic and bending fatigue tests

| TPNo. | Classification of ultrasonic test | Number of cycles | Without break |
|-------|-----------------------------------|------------------|---------------|
| F1    | B2 : Class1 (B1 : Class1)         | 2,000,000        | Yes           |
| F2    | B2 : Class1 (B1 : Class2)         | 2,000,000        | Yes           |
| F3    | B2 : Class1 (B1 : Class2)         | 2,000,000        | Yes           |
| F4    | B2 : Class2 (B1 : Class2)         | 350,000          | No            |

*1 B2 : Double-probe technique on rail base
B1 : Single-probe technique on rail base

5. Conclusions

Welding test results indicate that surface defects are not caused by rust on the rail surface. Rather, it appears they are due to gas generated from contact between luting sand and molten steel which then enters gaps between the welding mold and the rail surface. Results also showed that blowholes could be prevented by filling the gap between rail and mold with paste. Step molds are recommended for welding rails with a height difference of over 3 mm, because such large gaps are difficult to fill completely using paste.

This paper also suggests that the soundness of the base area of a thermit weld should be evaluated using a double probe technique in ultrasonic tests, regardless of the existence of surface defects. Finally, it is suggested that welds with defects smaller than class 1 defects should be evaluated as successful.

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