Effect of Non-metallic Inclusion of Flange Cracking of Drawn and Ironed Can from Tinplate*

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Synopsis

Flange cracking of Drawn and Ironed can from tinplate is caused mainly by non-metallic inclusions in the end of the can. In this study, the chemical composition and the minimum size of non-metallic inclusions causing flange cracking in tinplate of Al-killed steel were examined. The chemical composition of non-metallic inclusions is composed of $\text{CaO-Al}_2\text{O}_3$ and the minimum size is $5\text{ }\mu\text{m}$ in thickness and $50\text{ }\mu\text{m}$ in width. Countermeasures for reducing inclusions were taken in the continuous casting process, and the tinplate quality was inspected by a magnetic inclusion detector, thus leading to a reduction in the flange cracking rate of Drawn and Ironed cans.

I. Introduction

Drawn and Ironed can (D & I can) is a two-piece can in which the wall and bottom is made out of one piece. Recently the number of D & I can for carbonated beverages has been increasing because of its light weight, excellent quality and high productivity.

The required material properties of tinplate for D & I cans are good deep drawability, ironability, and flangeability. A material which satisfies these requirements is batch annealed Al-killed steel, that is, temper = T-1, thickness = $0.32\sim 0.34\text{ mm}$, tin coating weight = 0.75 lb/BB (8.4 g/m^2) for inner can wall and 0.5 lb/BB (5.6 g/m^2) for outer can wall.

One of the major problems of can forming is flange cracking. Flange cracking is caused mainly by non-metallic inclusions in the can ends.

A typical example of flange cracking is shown in Photo. 1. Non-metallic inclusions which exist in fractured flange was examined by an Electron Probe Micro Analyzer (E.P.M.A.). The chemical composition and percentage of the inclusions detected in the fractured flanges are $\text{CaO-Al}_2\text{O}_3$: 70 %, Al_2O_3 : 20 %, and SiO_2 : 10 %, respectively as shown in Table 1.

Can manufacturers have placed a requirement to reduce inclusions and to reduce the rate of flange cracking to less than 100 ppm (=less than 1 can per 10 000 cans).

In order to prevent flange cracking, it is necessary to reduce the number of inclusions in the steel making process and to eliminate coils having many inclusions by using the Ultra Sonic Testing (U.S.T.) or other methods in hot rolling and cold rolling processes.

In order to develop these countermeasures, it is necessary to clarify the minimum inclusion size which causes flange cracking. In this study, the relationship between the inclusion size and the limiting flanging rate for D & I can was investigated by previously detecting inclusions in a tinplate using a Magnetic

Inclusion Detector (M.I.D.) and by preparing the specimens in which the detected inclusion was located in the flanging portion of a D & I can.

II. Inclusion Size Which Causes Flange Cracking

The minimum inclusion size which causes flange cracking has been assumed to be around $100\text{ }\mu\text{m}$ in a continuous casting slab.¹⁾ This is deduced from inclusion size information detected by U.S.T., since the flange cracking rate is strongly related to the number of defects detected by U.S.T. in a slab.

In this study, in order to clarify directly the minimum size of inclusions for flange cracking, inclusions were detected by the M.I.D. on the tinplate and a blank was cut in such a way that it contained the inclusion. A D & I can was formed using the blank and was trimmed up to the inclusion location where the inclusion size was measured. Then the limiting flanging rate was measured.

1. Experimental Procedure

The material used was Al-killed steel, temper = T-1, tin coating weight = $0.75/0.50\text{ lb/BB}$, with its chemical composition and mechanical properties shown in Table 2. Tinplate for D & I cans usually contain very few inclusions, so their detection is difficult. In this experiment, a tinplate that is obtained from the top slab produced by continuous casting usually contains many inclusions.

Figure 1 shows the experimental procedure. De-

Table 1. Composition of inclusions which exist in fractured flange.

Composition of Inclusion	$\text{CaO-Al}_2\text{O}_3$	Al_2O_3	SiO_2	Total
Number	38	13	4	55
Ratio (%)	69.1	23.6	7.3	100

Table 2. Chemical composition (wt%) and mechanical properties of material used.

C	Mn	P	S	sol. Al	N
0.051	0.36	0.014	0.018	0.054	0.0055
t (mm)	HR30T	YS (kgf/mm ²)	TS (kgf/mm ²)	El (%)	$\bar{r}$
0.32	51.0	22.4	36.9	43.0	1.13

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Photo. 1.
The example of flange cracking in D & I can.

Fig. 1. Experimental procedure.

tails are as follows.

(1) Inclusion detection: Inclusions in the tinplate were detected by the M.I.D. One group of inclusions was used to carry out the following steps of this experiment. The other group was used in the measuring of their size after cutting and polishing in the transverse direction.

(2) Marking: Position of inclusions were marked by electrolytic etching.

(3) Blanking: The blank was cut such that the inclusion was located at 60 mm from the blank's cen-

ter in the rolling direction. These blanks had a diameter of 135 mm; 100 such specimens were prepared.

(4) Drawing and Ironing: A cup was made from these blanks by drawing and the can wall was ironed under such conditions as shown in Table 3. The final can wall thickness was 0.15 mm which is the same as the thickness of ends of commercial cans.

(5) Trimming: After ironing, the can wall was trimmed up to the location of the inclusion, the trimmed edge was polished, and the size of the inclusion was measured by an optical microscope.

(6) Stretch Flanging: Flanging was done by a special instrument shown in Fig. 2. The flanging rate was increased from 2.8 to 8.8 % with a step of 1.5 % until cracking occurred.

(7) Inspection: Fractured flanges were inspected by the E.P.M.A. to measure the composition of the inclusions.

With these investigations, the change of inclusion size due to drawing was observed by comparing the result of steps (1) and (5). The relation between the inclusion size and the limiting flanging rate became clear with the result of steps (5) and (6). The effect of can wall thickness on flange cracking was investigated by varying the wall thickness to 0.19, 0.15 and 0.11 mm.

2. Results and Discussion

1. Non-metallic Inclusion in Tinplate Detected by the Magnetic Inclusion Detector

Photograph 2 shows an example of an inclusion

detected by the M.I.D. which appeared in a cross section of the transverse direction.

In using the Magnetic Inclusion Detection, there was more accumulation of magnetic powder at the inclusion location than the surrounding area, as shown in Photo. 2. The length of the area where the accumulation of powder was denser was usually between 0.5 mm and 2 mm.

Where the accumulation of magnetic powder was higher than normal, inclusions were found. The chemical composition of the inclusions was CaO-Al₂O₃ and Al₂O₃. This is the same composition as that of inclusions detected in the fractured flange of D & I can, as shown in Table 1.

The distribution of inclusion size detected by M.I.D. in the tinplate is shown in Fig. 3. The thickness of inclusions ranged from 5 to 30 μm with an average of 10.5 μm. The width of inclusions ranged from 30 to 130 μm with an average of 84 μm. The location of the inclusions from the surface varied from

Table 3. Drawing and ironing conditions.

Process	Punch-dia. (mmφ)	Die-dia. (mmφ)	Lubricant	Can-wall thickness (mm)	Can height (mm)	Ironing rate (%)
Drawing	95.0	95.8	Outside } Press oil, #640 Inside }	0.34~0.32	24	
Redrawing	66.0	66.80		0.33	54	0
1st-ironing	„	66.60	Outside Press oil, #640	0.30	58	6.3
2nd-ironing	„	66.46		0.23	74	28.1
3rd-ironing	„	66.38	Inside Rust preventing oil	0.19	87	40.6
4th-ironing	„	66.30		0.15	109	53.1

Fig. 2. Instrument for flanging.

Photo. 2.
The example of inclusion detected
by the M.I.D.

30 to 160 μm which was about 1/10 to 1/2 of the thickness of the tinplate.

2. Inclusion in the Trimmed Edge after D & I Can Forming

Figure 4 shows the distribution of inclusion size at the trimmed edge after D & I can forming in the case of 0.15 mm can wall thickness.

The thickness of inclusions ranged from 5 to 35 μm with an average of 12.2 μm , and these are similar to those found before drawing. The width of inclusions ranged from 10 to 100 μm with an average of 51 μm . The width of these inclusions was contracted by about 40 % in deep drawing. This decrease in the width is considered to be the result of circumferential shrinkage due to drawing and redrawing of the blank to reduce the radius of the inclusion location from 60 to 33 mm.

3. Effect of Inclusion Size on Limiting Flanging Rate of D & I Can

Figure 5 shows the effect of inclusion size on the

Fig. 3. Inclusion size detected by the M.I.D. in the tinplate.

Fig. 5. Effect of inclusion size on the limiting flanging rate.

Fig. 4. Inclusion size at the trimmed edge after D & I can forming.

forming, the flange cracking rate increases with a longer inclusion, because longer inclusions have a greater probability of existing on the trimmed edge.

4. Effect of Depth and Composition of Inclusions on Limiting Flanging Rate

Figure 6 shows the effect of inclusion depth on the limiting flanging rate. Though the effect of inclusion depth on limiting flanging rate is not clear, the limiting flanging rate does tend to decrease as inclusions exist on the surface.

In this experiment, the composition of the inclusions was $\text{CaO-Al}_2\text{O}_3$ and Al_2O_3 , but it had no influence on flange cracking. In another experiment of rimmed steel, the inclusion of MnO and $\text{Al}_2\text{O}_3\text{-SiO}_2\text{-MnO}$ was examined. In that experiment, the inclusion size and limiting flanging rate showed the same tendency as in this experiment. Therefore, it can probably be concluded that the composition of inclusion has no influence on flange cracking.

5. Effect of Wall Thickness on Limiting Flanging Rate

Figure 7 shows the variation of limiting flanging rate for the can wall thickness of 0.19, 0.15 and 0.11 mm. The limiting flanging rate decreases as the wall thickness becomes smaller.

In the future, when the can wall thickness becomes thinner in order to reduce can weight, the problem of flange cracking will become more serious. Therefore, inclusions should be reduced below that of today's level.

III. Countermeasures for Reducing Inclusions in Steel Making Process

From these experiments, the size of inclusions which cause flange cracking of D & I cans was more than 50 μm of width of tinplates. The width of inclusions does not change during hot rolling and cold rolling. Therefore, the limiting size of inclusions for flange cracking can be concluded to be more than 50 μm in diameter in continuous casting (c.c.) slab.

Figure 8 shows the distribution of inclusion size in c.c. slabs and the limiting size of inclusions which caused various defects in final products. The number of inclusions over 100 μm is relatively small, but there

Fig. 6. Effect of inclusion depth on the limiting flanging rate.

are many inclusions which are smaller than 100 μm in size.

As shown in Fig. 8, such surface defects as sliver and point defects in tinplate are caused by inclusions approximately $500\text{ }\mu\text{m}$ and $400\text{ }\mu\text{m}$, respectively. The U.S.T. defects in U.O.E. and E.R.W. pipes are caused by inclusions over approximately $200\text{ }\mu\text{m}$. However, flange cracking of D & I can is caused by such small inclusions over $50\text{ }\mu\text{m}$ in size. Therefore, more severe countermeasures are necessary for reducing inclusions for Al-killed steel for D & I can than for general applications.

As shown in Table 1, the percentage breakdown of the composition of inclusions found in fractured flange was 70 % $\text{CaO-Al}_2\text{O}_3$ and 20 % Al_2O_3 .

$\text{CaO-Al}_2\text{O}_3$ inclusions are considered to be pro-

Fig. 7. Variation of limiting flanging rate by the can wall thickness.

Fig. 8. Limiting size of inclusions which caused various defects in final products.

duced by a reaction between reducible SiO₂ in converter slag particles (CaO-SiO₂) suspended in molten steel and Al. Al₂O₃ group inclusions are considered to be products of air reoxidation. The growth mechanism of these inclusions is thought to be the coagulation of inclusion in molten steel, and the depositing of inclusions on the inner wall of the submerged nozzle.

Based on these considerations, countermeasures used for reducing inclusions are shown in Fig. 9.

(1) Purification of molten steel in a ladle: In order to prevent BOF slag from flowing out to the ladle, slag was cut off from flowing out at tapping by plugging the outlet with a round refractory (so called "slag cutting"), and synthetic slag was added.

(2) Prevention of reoxidation of molten steel during teaming from a ladle to a tundish: Teaming molten steel was sealed by a long submerged nozzle during casting.

(3) Improvement of tundish structure: To prevent the erosion of refractories of the tundish, magnesia (MgO) was coated over the entire inner wall. To accelerate the floatation of inclusions, the weirs were set, and the tundish volume was enlarged.

(4) Ar gas injection into submerged nozzle: To prevent the large deposition of inclusions on the inner wall of the nozzle, Ar gas was injected through the

Fig. 9. Countermeasures for reducing inclusion on continuous casting.

Table 4. Effect of countermeasures for reducing inclusions.

Countermeasures			Defect of U.S.T	Defect of M.I.D	Flange cracking of D & I can
Non-oxidation casting	Tundish improvement	Ar gas injection			
○	×	×	100	—	100
○	○	×	55	100	43
○	○	○	7	4	17

tundish stopper as shown in Fig. 9.

The effects of these countermeasures for reducing inclusions are shown in Table 4. Inclusions were reduced markedly by the combination of these countermeasures.

IV. Detecting Method of Inclusions

Despite the fact that these countermeasures were taken to reduce inclusions as explained in the previous section, inclusions still were sometimes found in the steel.

In order to detect these inclusions on tinplate, the M.I.D. was used. Ten sheets of tinplate (width×500 mm) were cut from the head and tail of the coil, and these sheets were examined for inclusions by visual inspection.

The size of the inclusions which the M.I.D. was able to detect was more than 500 μm in length. Small inclusions less than 500 μm in length were difficult to distinguish from the surrounding magnetic powder. Inclusions detected by the M.I.D. were more than 5 μm in thickness and 30 μm in width as shown in Fig. 3. The composition of these inclusions was CaO-Al₂O₃ and Al₂O₃, the same as the inclusions detected on fractured flange in the D & I can.

Figure 10 shows relationship between the number of defects detected by the M.I.D. and the flange cracking rate which was provided by a commercial can manufacturer. The flange cracking rate increases with an increase in defects. When the defective rate is 0.5/m², the flange cracking rate is about 100 ppm. Therefore, to reduce the flange cracking rate to less than 100 ppm in can making, coils which contain more than 0.5 inclusions/m² have been rejected for use at Fukuyama Works.

Countermeasures for reducing inclusions are taken in the steel making process and the tinplate quality is inspected by the M.I.D., thus leading to a reduction in the flange cracking rate of D & I cans.

V. Conclusion

Size and composition of inclusions which cause flange cracking of D & I cans were investigated and

Fig. 10. Relationship between the number of defects detected by the M.I.D. and the flange cracking rate of D & I can.

countermeasures for reducing inclusions and detecting method of inclusions were considered.

(1) The minimum inclusion size which causes flange cracking of D & I cans is $5\text{ }\mu\text{m}$ in thickness and $50\text{ }\mu\text{m}$ in width of tinplate. This size is very small compared with conventional inclusions which cause surface defects in tinplate.

(2) Inclusions are composed mainly of $\text{CaO-Al}_2\text{O}_3$ and, to a lesser degree, Al_2O_3 . Composition has no effect on flange cracking.

(3) When the inclusion size is comparable, the limiting flanging rate becomes smaller as the can wall thickness becomes thinner.

(4) Countermeasures such as slag cutting, setting

of an air sealed pipe, improvement in tundish, and Ar gas injection into tundish nozzle are effective for reducing inclusions in the continuous casting process.

(5) Detection of inclusions using a magnetic inclusion detector can eliminate unsuitable coils for D & I cans.

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