Development of the World's First Defective Flute Image Inspection System for Corrugated Cardboard

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Mitsubishi Heavy Industries Machinery Systems, Ltd. (MHI-MS) has successfully developed and commercialized a new image inspection system for defective flutes in corrugated cardboard, utilizing image processing technologies for the first time in the world. We have become able to detect defective flute shaping stably and accurately by taking advantage of image processing technologies to meet the needs of customers who want to prevent defective flute cardboard during production. The introduction of this inspection system reduces jamming of corrugated cardboards with insufficient strength due to defective flute. Furthermore, there is no more need for recalls or production do-overs, which used to be caused by the mixing of defective corrugated cardboards into later processes, which has significantly improved the corrugated cardboards productivity of corrugators. Currently, this new inspection system has received positive reviews from many customers as the world's first breakthrough in the corrugated cardboard industry and has already been introduced and is operating smoothly in 9 customer plants Japan and overseas.

1. Introduction

In the corrugated cardboard industry, there has been an increase in the number of orders for multiple different types in small batches with quick delivery times. Meanwhile, with respect to corrugators which produce corrugated cardboard, when corrugated cardboards with insufficient strength are manufactured due to defective shaping of the wavy flutes, which is called the corrugating medium, the corrugated cardboard could become bent on the stacker's conveyer belt in the final corrugator process. Subsequent sheets can get stuck and pile up, causing a paper jam which could result in a machine shutdown requiring many hours for recovery. Furthermore, the mixing of defective flute cardboard with insufficient strength in later production processes could cause recalls and production do-overs, which significantly lowers the corrugator's cardboard productivity. Under such circumstances, there is significant customer demand to prevent the mixing of defective flute cardboard in the production line. To meet this need, MHI-MS has successfully developed and commercialized the world's first defective flute image inspection system that detects defective flute shaping stably and accurately, utilizing image processing technologies.

2. Defective flute shaping in the corrugator

In a corrugator, corrugated cardboard is manufactured in the corrugated cardboard production process as shown in **Figure 1**, where the flutes in the corrugating medium are first formed by the corrugating rolls in the single facer. Next, the flutes in the corrugating medium and the liner are glued together by the pressing belt, which is how single-faced corrugated cardboards are manufactured. In this process of manufacturing single-faced corrugated cardboards in the single facer, defective flute could occur due to various different factors such as insufficient pressure by

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the corrugating rolls at the time of flute shaping and gluing, inadequate heat or glue, etc. **Figure 2** shows one example of defective flute shaping where the flutes in the corrugating medium are crushed due to failure in gluing, causing irregularities in the flute height.

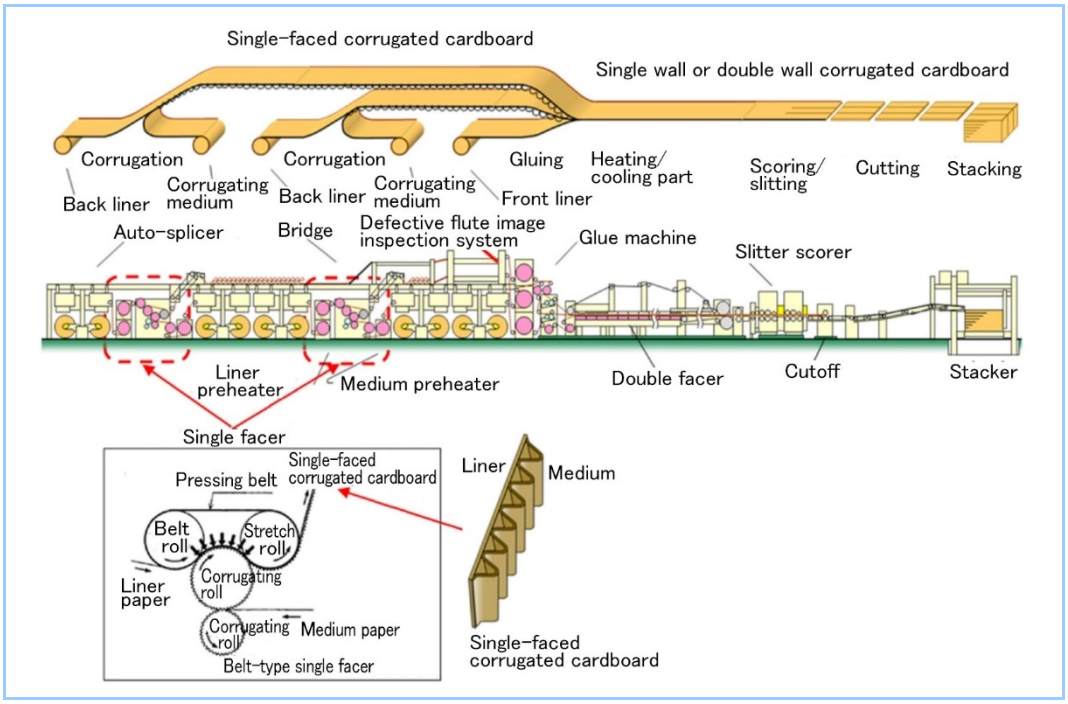

Figure 1 Corrugated cardboard production process in a corrugator

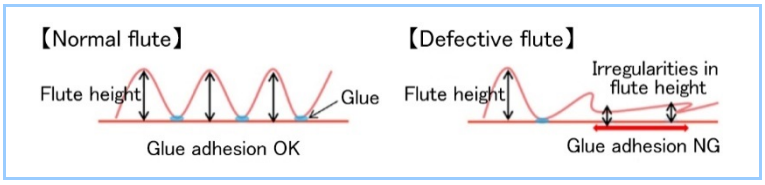

Figure 2 Example of defective flute shaping

3. Overview of defective flute image inspection system

3.1 Installation location

In order to carry out inspection by using a camera to capture images of the side of the single-faced corrugated cardboard that faces the corrugating medium after the corrugated cardboard is completed, as shown in the installation location in **Figure 3**, a camera and light are installed on the bridge just before the glue machine which comes after the single facers. When a defective flute is detected, it will be automatically removed by the defect remover located before the stacker in the later process by tracking the defect and its travel route. Furthermore, **Figure 4** is an installation drawing for the camera and light, depicting an example of a typical corrugator line which can manufacture up to double wall. **Figure 5** is a photograph of the actual machine.

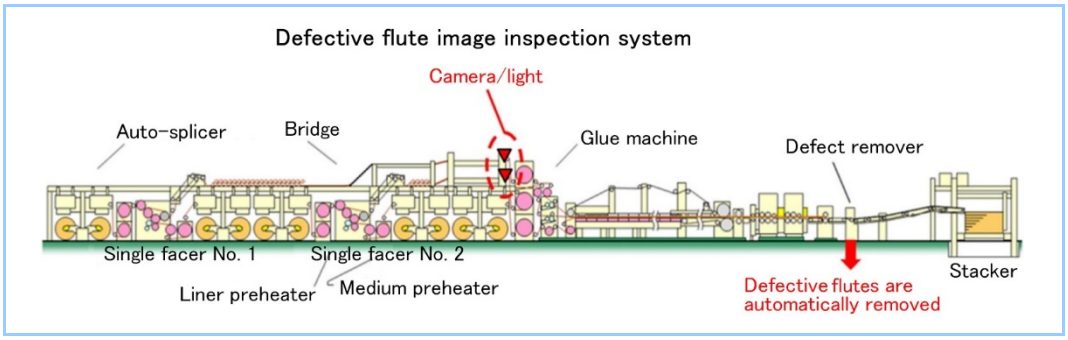

Figure 3 Installation location

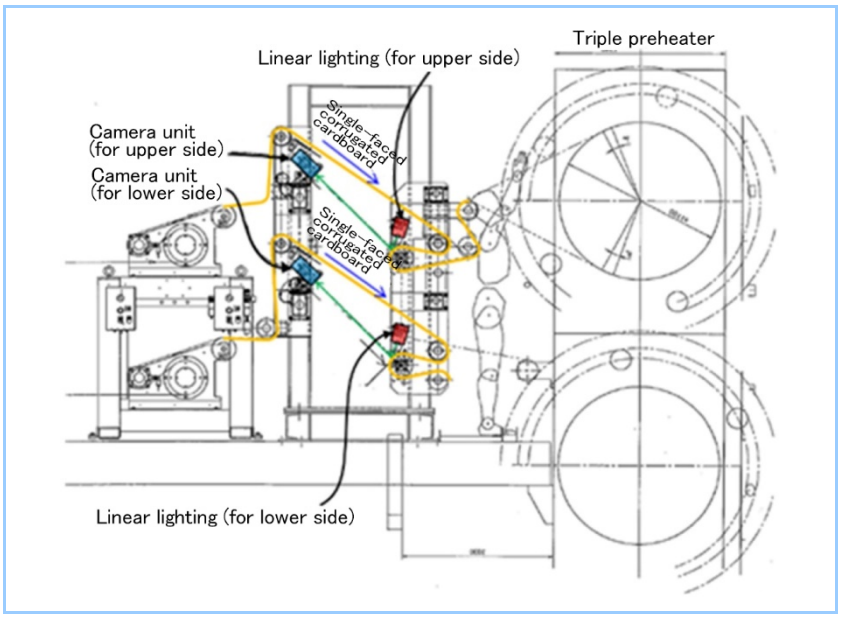

Figure 4 Machine installation

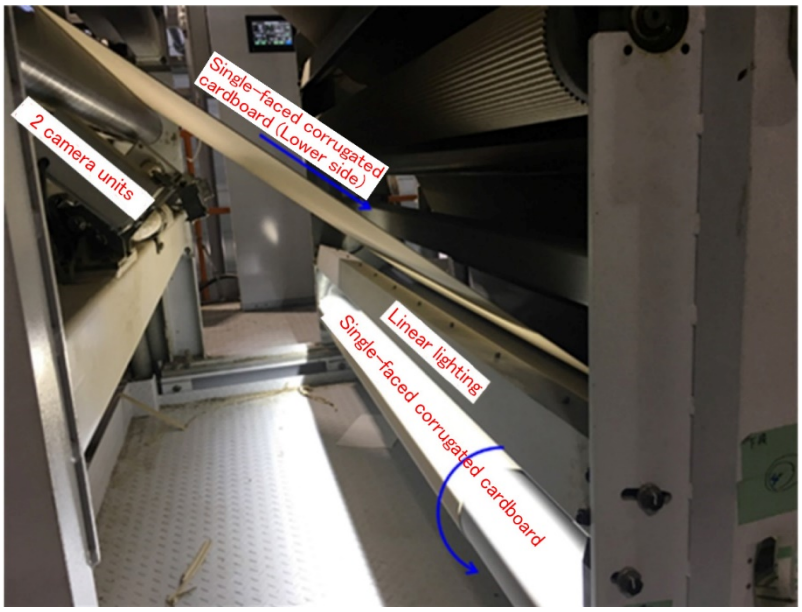

Figure 5 Photograph of actual machine

3.2 System configuration

As shown in the configuration diagram in **Figure 6**, this inspection system consists of various components in addition to the camera and light, such as the control panel in which the image processing device is stored and a defect-image display screen for the operator's use installed in the stacker area. When any defect is detected, an alarm lamp informs operators in different locations by activating an alarm light and buzzer, and the image captured of the defect appears instantly on the defect-image display screen situated in the stacker area. Furthermore, when a defect is detected, the detection signal is sent instantly to the corrugator production management system, which tracks the position of the defective flute and removes it as soon as it reaches to the defect remover.

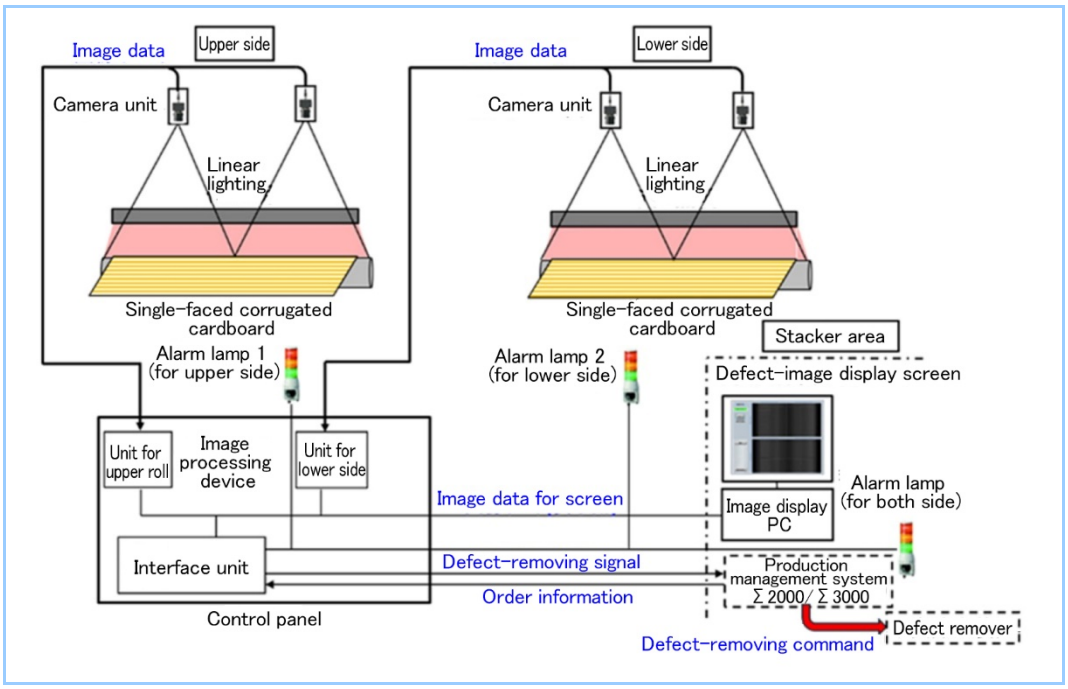

Figure 6 System configuration

4. Features of defective flute image inspection system

4.1 Stable and highly-accurate inspection with image processing

As shown in the measurement principle chart in **Figure 7**, the basic principle of the system is to detect irregularities in the flute height due to defective flute shaping based on variations in the width (length) of the bright section and the dark section in the image data of the light-dark portion generated by illuminating a single-faced corrugated cardboard with linear lighting at an angle. The borders between the bright and dark bands in individual flutes are identified through black-and-white edge extraction by image processing and thus the distance between the edges is measured. Consequently, if the measurements are outside of the acceptable range with reference to the nominal value, the flute section is determined as defective. Meanwhile, with regard to the nominal value used for determining defects, the system stores basic parameters and the acceptable range for each thickness type of corrugated cardboard with a different flute height (A, B, C and E). However, even when the thickness type is the same, there are still some variations in the measurements depending on the type of paper. Therefore, the acceptable range needs to be set wide, which has been an issue in high-accuracy inspection. As shown in **Figure 8**, we conducted auto-tuning where the maximum and minimum values in the acceptable range corresponding to the nominal value are automatically adjusted to the optimal level depending on the extent of variations in the flute measurements at the time of changing paper type. The system learns through this auto-tuning and has become capable of highly-accurate and stable inspection.

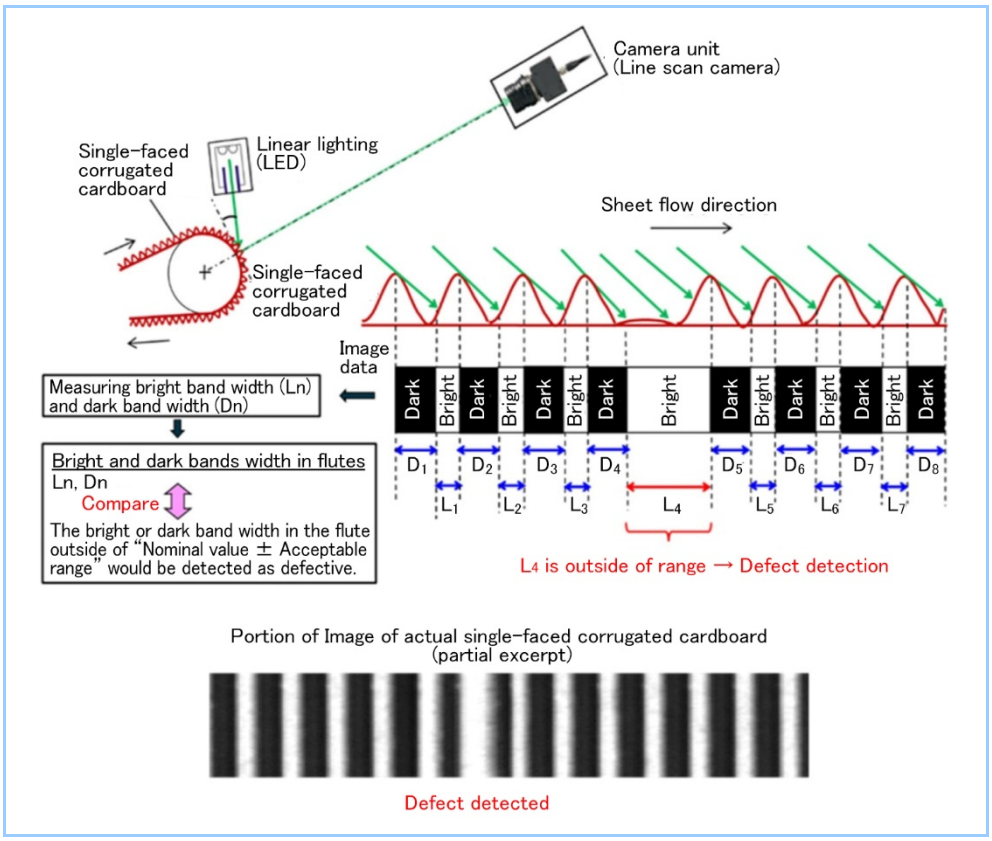

Figure 7 Measurement principle

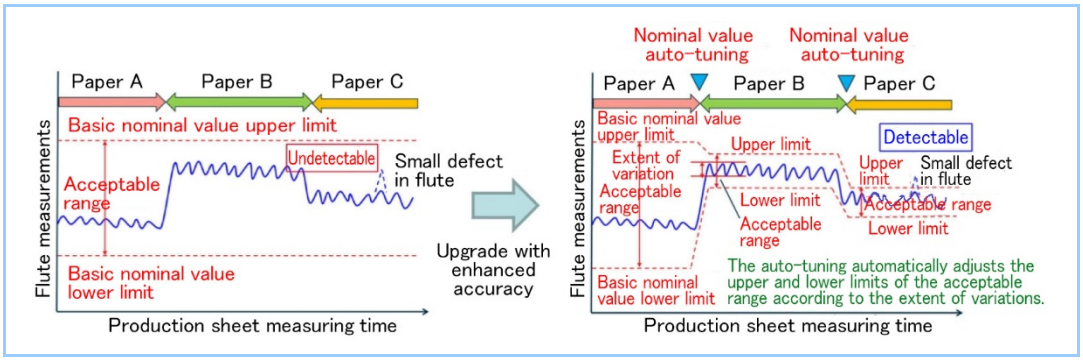

Figure 8 Concept of nominal value auto-tuning

4.2 Visualization of flute defects

Since customers have a need to clarify the cause of defects through visualizing the conditions of flute defects to make use of in the maintenance of the machine and in taking preventive steps, we developed an additional feature to display images of defects on a screen, taking advantage of the fact that this inspection system utilizes image processing. Firstly, as shown in **Figure 9**, when detecting a flute defect, the operator is able to identify where and what kind of defect has occurred instantly by displaying the image of the defective flute on the defect-image display screen in real time and highlighting the location where the flute defect is detected. Furthermore, as shown in **Figure 10**, images of other flute defects that have occurred in the past are also stored in the history log. Images of a defect on a certain date could be retrieved from the defect history log and shown at a later date. Therefore, even when a defect couldn't be examined immediately during operation, it is still possible to review the type of defect and its location later and utilize the information for recurrence prevention by reflecting the information in machine maintenance.

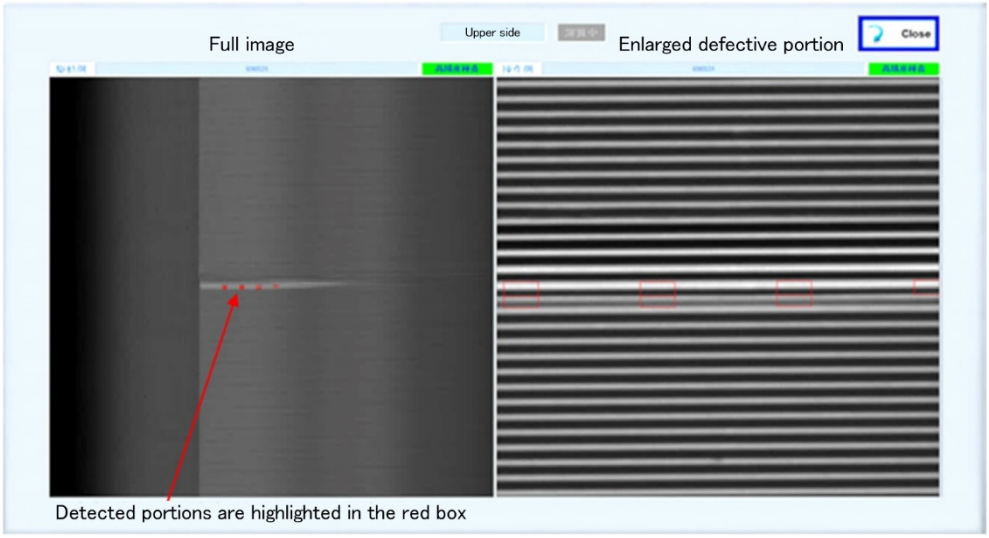

Figure 9 Real-time defect-image display

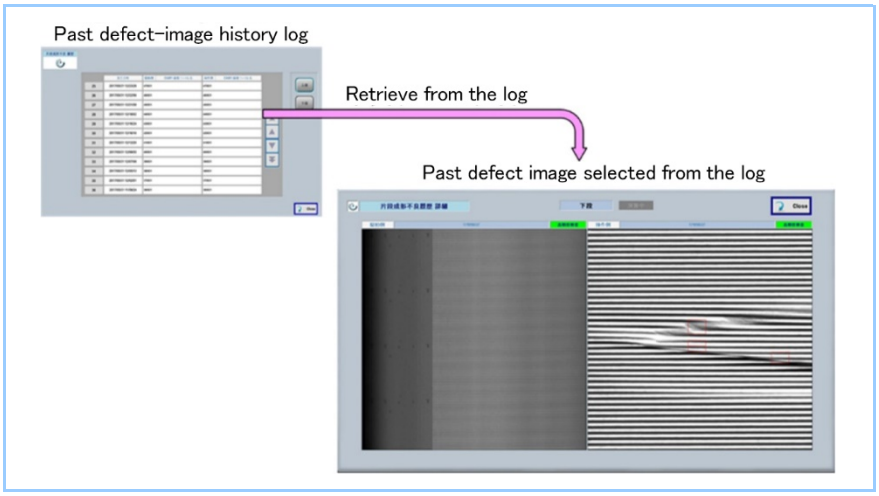

Figure 10 Past defect-images log

5. Example of actual flute defects

Figure 11 shows some typical defects actually detected at customer plants. Images of defects detected are on the left side, while those on the right side are the defective flutes after removal. Defective flutes caused by faulty machine settings in the individual conditions were detected.

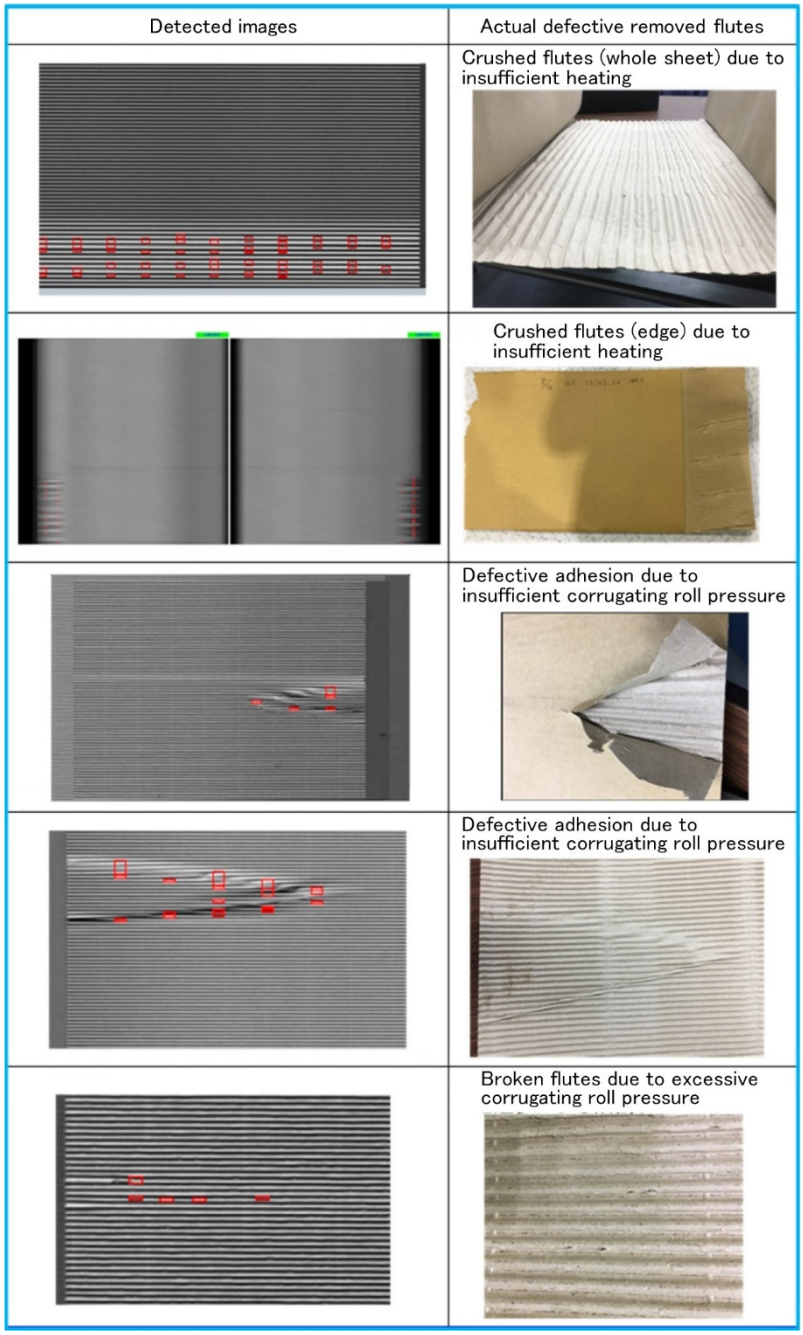

Figure 11 Sample of Aactual defects detected

6. Conclusion

This defective flute image inspection system is capable of detecting defective flute shaping stably with high accuracy by utilizing image processing technologies. However, since making our first delivery of this system, we have worked on not only boosting its performance, but also various other improvements, such as adding new features and enhancing operability. These efforts have been based on a significant amount of user feedback and input from our customers, which has led to the system's high-quality finished product.

The customers who installed this inspection system have highly evaluated it, as paper jamming caused by corrugated cardboards with insufficient strength due to defective flute has been reduced and there is no more need for recalls or production do-overs, which used to be caused by the mixing of defective corrugated cardboards into later processes, and this has significantly improved the sheet productivity of corrugators. We have also received many enquiries about potential orders for this machine as the industry's first ground-breaking inspection system. It has already been installed and is operating smoothly in 9 customer plants Japan and overseas. In the future, we will continue to develop new products suiting the needs of customers in corrugated

cardboard production.

References

(1) Introduction of Mitsubishi Heavy Industries Camera-Type Defective Flute Detector for Single Faced Cardboard, Japan Corrugated Case Association, Corrugated Cardboard Seminar 2017, Proceedings p.45～47