Evaluation of Defects in the Bonded Area of Shoes using an Infrared Thermal Vision Camera

Jae-Yeol Kim, Dong-Jo Yang, and Chang-Hyun Kim

Abstract: The Infrared Camera usually detects only Infrared waves emitted from the light in order to illustrate the temperature distribution. An Infrared diagnosis system can be applied to various fields. But the defect discrimination can be automatic or mechanized in the special shoes total inspection system. This study introduces a method for special shoes nondestructive total inspection. Performance of the proposed method is shown through thermo-Image.

Keywords: Infrared thermal vision camera, shoes, evaluation of defects, heating system.

1. INTRODUCTON

The defect inspection system plays an important role in actual inspections. Specifically, the nondestructive inspection system has developed rapidly in recent years. In this system, an infrared thermal vision camera is utilized for simple inspections, and the user can conveniently obtain reasonably accurate data. Presently, the total inspection system for special shoes cannot detect defects automatically or mechanically, so studies on the new nondestructive inspection system using an infrared thermal vision camera have received much attention. We used an infrared thermal image camera, Thermo-vision 900 manufactured by AGEMA Co., to carry out a basic study of two specimens that were made of the same material used in the bonded part of a special shoe and that was implanted (or imbedded) with two different artificial defects, respectively. The thermal images of the specimens were analyzed. In shoes, weak bonding due to the separation of the bonded parts delamination causes defects. The most serious defect occurs in the bonding between the outer covering of the shoe and the sole, and to up now, this defect has been detected only by inspection with the naked eye. In search of superior inspection methods, we evaluated an applicable non-destructive inspection method and also carried out basic research for developing an innovative nondestructive inspection system for special shoes. Throughout the process, we also focused on the development of a heating system that can uniformly heat the specimen during thermal nondestructive inspection. The total inspection system using infrared thermal camera for special shoes, its applicability, and system configuration are introduced.

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2. THERMAL MEASUREMENT THEORY

We used the Thermo-vision 900 SE/TE manufactured by AGEMA as the infrared camera, able to detect infrared waves from the various light waves emitted from an object. Using the detected infrared waves, the detector measures the thermal distribution of the object. By definition, a body that absorbs any type of wave directed to it is called a blackbody, and it can also discharge the wave. The essential factors of thermal detection are the object, its temperature, and emissivity that changes according to distance. The variance in emissivity value is used to measure the temperature. An infrared thermal camera is a device that detects the infrared waves reflected from an object shone on by an external light source and expresses these waves as a function of temperature by using the Stefan-Boltzmann Law to display temperature fluctuations. The relation between wave and temperature is expressed by the equation:

$$E = \varepsilon\sigma T^4 , \qquad (1)$$

The first term on the right-hand side represents the radiation from the object, the second term represents the emitted radiation reflected from the surrounding

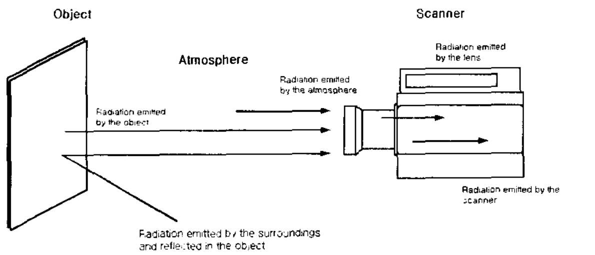


Fig. 1. Radiation contributions to the general measurement situation.

$$I_m = I(T_{obj}) \times \tau \times \varepsilon + \tau(1-\varepsilon) \times I(T_{amb}) + (1-\tau) \times I(T_{atm}). \quad (2)$$

area, and the third term represents the air radiation. The thermal value of the total measured radiation can be expressed by (2). The Thermo-vision 900 infrared camera measures and extracts only the infrared wave radiation lying within a certain spectral range and then converts the infrared energy into electrical energy, which is used to generate a thermal image. The governing equation to carry out this extraction and conversion in the scanner is the same as (2) and the system controller has been incorporated in the ERIKA software. The Thermo-vision 900 automatically processes this equation, but the scanner operator must input other parameters related to the present measurement environment, such as radiation, distance to the object, relative humidity, ambient temperature, reflected surrounding temperature, etc. The correction factors are stored in the scanner, and the system selects an appropriate correction factor for the combination that is automatically used. The correction function uses Plank's Law and the spectral responses of the filter and scanner to correct for the combination of lens, filter, and range are used, but more accurate corrections can be obtained by actually measuring a large number of blackbody sources. Without considering the exact temperature distribution by accounting for the different radiation rates of materials, we confirmed the relative temperature distribution by setting one radiation rate for all parts. The calibration function could be calculated using Plank's Law and the spectral response of the scanner and filter, however, a much more accurate result is achieved through measurement. This is done during calibration when a number of blackbody sources are measured using the scanner.

3. INFRARED THERMAL VISION CAMERA

Thermo-vision 900, the infrared thermal imaging camera system used in our study, is the 6th-generation infrared scanning system, manufactured by AGEMA infrared system AB. Using the latest technology, AGEMA reduced the scanner size and inserted analytical functions and controls in the system controller, designed to be operated from a windows menu environment. The system controller has two 68020 processors, a 32-bit VME bus, and two 16-bit IR buses. The scanner has the following features: thermoelectric cooling; detection in the form of a two-split serial-scaling 2~5.4 micron spectrum response; temperature range between -10 ~ 500 (detects up to 2000 using a high-temperature filter); sensitivity of 0.1 at 30℃; spatial resolution of 140 pixels/line(50% modulation); IR line frequency of 3.5Khz; and a simple/line of 204. Fig. 2 shows a diagram of the infrared thermal imaging camera used in our study. The Thermo-vision 900 temperature detection camera system includes a notebook PC card and camera for convenient portability, power scanner for PC card connection, and power supply.

Fig. 2. The Thermo-vision 900 system.

4. HEATING SYSTEM

When the infrared thermal imaging camera is used to capture an image, the specimen must be heated to a temperature higher or cooled to a temperature lower than the ambient temperature. Knowing this fact, we must build a heating system capable of applying uniform heat to the specimen. This heating system must be designed so that it transfers uniform temperature to the specimen surface. If the specimen does not come into direct contact with the heat panel, the gap that is created will prevent uniform heat transfer. This non-uniform heat transfer will alter the temperature value in the final measurement image and defects will be difficult to detect. To solve this problem, we placed the specimen at a fixed distance away from the heat panel and allowed the heat to move from the heat panels, through air, to the specimen. In this method, pressure does not need to be applied to the heat panel to make it come in contact with the specimen but rather heat convection through the air layer between the panel and the specimen is sufficient to transfer uniform heat from the panel to the specimen. The diagram of this heating system is shown in Fig. 3. Heat convection in

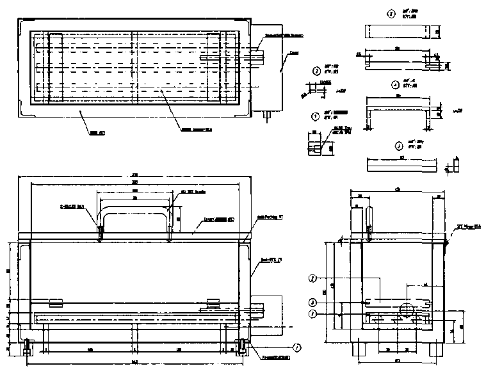


Fig. 3. Design of heating system.

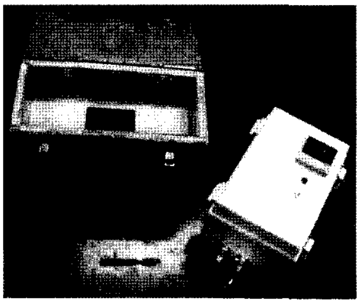
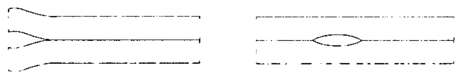
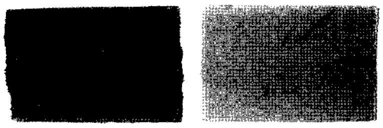


Fig. 4. Heating system.



a. Open Type b. Close Type

Fig. 5. Type of artificial defect.



a. Upper b. Sole

Fig. 6. Photo of a test sample.

the heating system itself raised the air temperature, so it was difficult to accurately measure the heat distribution of the specimen. As a measure, a jig was designed for the specimen and a thermocouple was attached to the heat panel. This thermocouple measured the temperature of the heat panel and not of the air. The controller was used to control the temperature. The entire heating system including the specimen and jig is shown in Fig. 4. In the heating box, ten hot wires were placed apart from each other at a fixed distance on the heat panel. To allow uniform heat transfer from the heat panel to the specimen, we placed the specimen 10 mm away from the heat panel. A guide to fix the specimen and a thermocouple to control the heat panel were connected. Furthermore, a separate control box to control the heat panel temperature was built. Also, to prevent the rise in temperature of the surrounding specimen due to heat convection, we assembled a wooden jig around the specimen.

5. DEFECT EVALUATION METHOD

The decisive defect in special shoes occurs in the bonding between the outer covering and the sole. Two types of artificial defects are the open defect and closed defect. Artificial defects such as that shown in Fig. 5 were created. The temperature distribution of the covering was measured to detect any defects. The temperature of the heat panel in the heating system was set to 90℃, which does not damage the shoe quality. The shoe was heated at this temperature for less than 5 min; this heating duplicates actual processing conditions. Two specimens were prepared: a 2-layer specimen consisting of two materials and a 3-layer specimen composed of three materials. Considering various combinations of shoe materials, bondings of various materials, defect types, and number of layers, we prepared a total of 31 specimens for evaluation. The same shoe was examined four times for defects in the exact locations in the front, back, right side and left side. The reliabilities of the measurements from these examinations were summed. An open defect can be detected with the eye so the defect was examined in one infrared image. A close defect, however, was found by comparing four images of the same specimen. In our study, the images of the open and close defects of 2-layer specimens taken from the bonding part between the shoe outer covering and sole - where typically the most number of defects are found - were compared. The heat distribution shown by these images were analyzed and the defect parts were determined. Because there was insufficient paper area, we used only the test specimens of the same material, shown in Fig. 6, to evaluate both open and closed defects.

5.1. Open-type defect evaluation

The open-type defect specimens were prepared with Sole (Rubber), cleanser (TCE), Preprocess (007), adhesive (5100A), and Upper (action). A defect between the two layers creates an opening, where an air pocket forms, and this air pocket lowers the heat transfer. The temperature of the layers will be low. As the temperature decreases, a dark portion on the thermal image will appear, indicating a defect. The defect evaluations and heat distribution interpretations in the infrared thermal images for the above specimens are shown below. In the left figure, an infrared thermal image depicts dark areas that indicate possible defects. A line was drawn across each dark area. The right figure illustrates the curve of the temperature distribution along the line. We can see that the curve changes in areas where there is a possible defect.

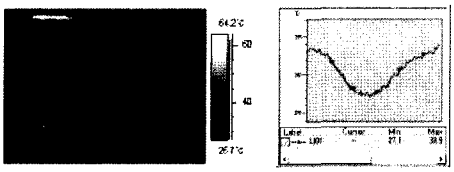


Fig. 7. IR image to sole up.

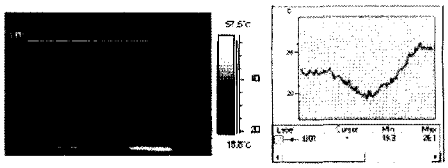


Fig. 8. IR image to upper up.

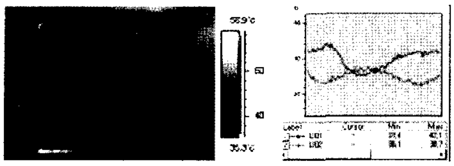


Fig. 9. 180° rotation image of Fig. 7.

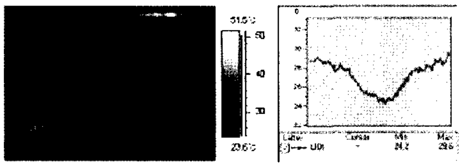


Fig. 10. 180° rotation image of Fig. 8.

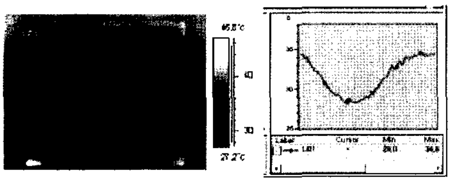


Fig. 11. IR image to sole up.

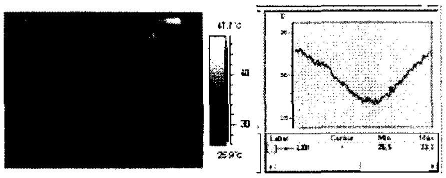


Fig. 12. IR image to upper up.

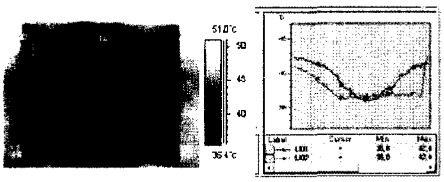


Fig. 13. 180° rotation image of Fig. 11.

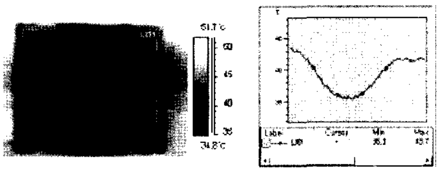


Fig. 14. 180° rotation image of Fig. 12.

5.2. Close-type defect evaluation

The same material used for open defect specimens was used to compose the close defect specimens. In other words, only the type of defect was changed. The left figure below shows the infrared thermal image and the right figure shows the curve of the temperature distribution of the line through a dark area on the image, which indicates a possible defect.

6. DISCUSSION AND RESULT

We used the infrared thermal imaging camera to study the open-type and close-type defects in 2-layer and 3-layer specimens. A total inspection system using infrared thermal imaging for special shoes can be developed. This inspection can be carried out by adding a process in the actual production line. The most daunting problem lies in the development of the heat system. In an actual production line, the inside of the shoe must be heated.

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