Thermo-graph inspection for geomembrane seam evaluation

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ABSTRACT: This study attempted to develop a new method for detecting failures on welded seams between geomembrane liners. To identify the location of faulty seams, thermal images taken by a thermo graphic device were used to determine the unique temperature distribution on the faulty seam. It was shown that the real-time inspection for detecting faulty area was possible by taking thermal images of the seams while the sheets were welded by a self-propelled heat-welding machine. This method is more efficient compared to the conventional inspection method as that the seam can be examined with the welding work.

1 INTRODUCTION

Landfill Liners fulfill the important role of preventing the leakage of the leachate in the landfill site. Geomembrane sheets are welded together for the construction of landfill liners. The seams between the sheets must be carefully inspected for faulty welds. There are various inspection methods such as Air Pressure Testing (APT) and Vacuum Box Testing (VBT). APT can only be applied to seams joined by double fusion welding, is easy and effective, but does not indicate the exact location of the fault. VBT is time-consuming if all the seams are to be inspected. A new viable method, which will complement the demerits of the existing methods, is therefore required.

This study attempted to develop Thermo-Graph Inspection (TGI) method employing a thermo graphic device as a tool for real-time inspection that the thermal images taken by the device were used to identify faulty seam.

2 EXPERIMENT

Figure 1 is a sectional view of a welded seam, and temperatures in welding are also shown. Surfaces of the sheet to be welded are heated to 400 ~ 500 Co by a self-propelled heat-welding machine. This heat reaches upper surface of the seam and it makes the temperature increase to 70~ 80 C^{o} (indoor condition). On a faulty seam, surface temperature shows the unique distribution since its heat transfer rate is different from the normal seam. The thermal image of the welded seam is expected to provide an evidence to detect faulty area on the seam[1),2)].

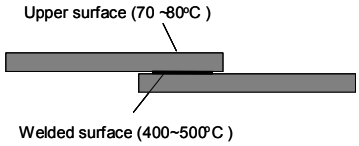

Fig. 1 Sectional view of a welded seam

2.1 *Samples*

High-density polyethylene (HDPE) sheets were welded together by double fusion welding using a self-propelled heat-welding machine. To construct a faulty area on the seam, samples like following were made; (1) seams with groove scratches (SU1-3, SL1-3), (2) seams that a foreign object (gummed tape) was held between the sheets (GU1-3, GL1-3). Figure 2 and figure 3shows an experimental sample which has faults on a seam.

2.2 *Experimental equipment*

Figure 4 shows the experimental equipment required for thermo-graph inspection. In this

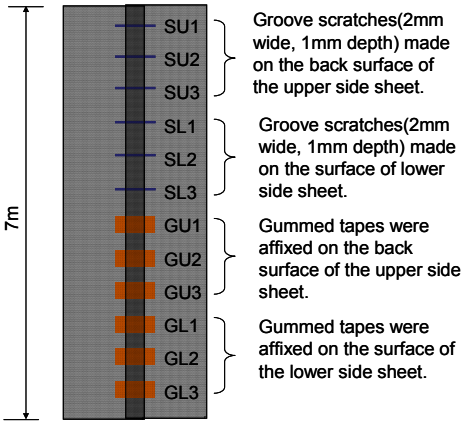

Fig. 2 Experimental sample which has faults on a seam

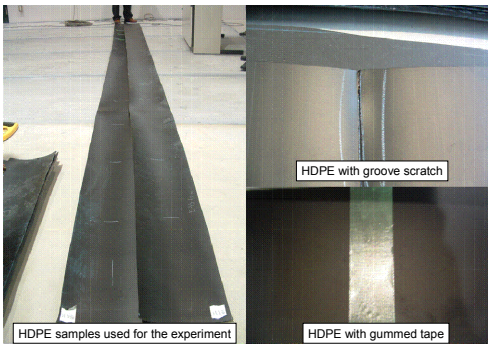

Fig. 3 Pictures of experimental samples

experiment, 2 sheets with faulty area were welded together by self-propelled heat-welding machine. The temperature in welding was 420~500°C, and the welding speed was 1.5~1.7m/min. A thermo graphic device was fixed on the welding machine. It took images of the surface temperature and saved it as video files, with the sheets were welded by the welding machine.

Figure 5 shows a view of a faulty seam detection software which was developed in this study. This software has 2 functions. The first function is the continuous recording of the temperature on the welded seam. The temperature of the area surrounded in the squares, which are named "monitoring frame" in Figure 5, was recorded as a csv file. A monitoring frame is composed of 9 cells, and the temperature of each cell can be recorded at 1 second interval. The second function of the software is faulty seam detection. Users of the software can set the range of the temperature of normal seam as threshold temperature. When the temperature in the monitoring frames become higher or lower than the normal range, the area is detected as a faulty seam.

The experiment was conducted indoors in an environment where both the ambient and sheet temperatures were approximately 23 °C. A scene of the experiment is shown in Figure 6.

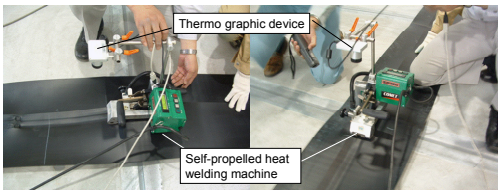

Fig. 4 A self-propelled heat welding machine with a thermo graphic device

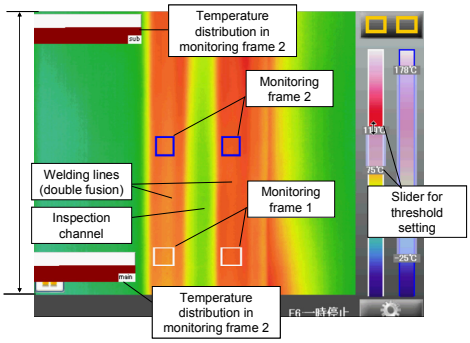

Fig. 5 A view of the faulty seam detection software

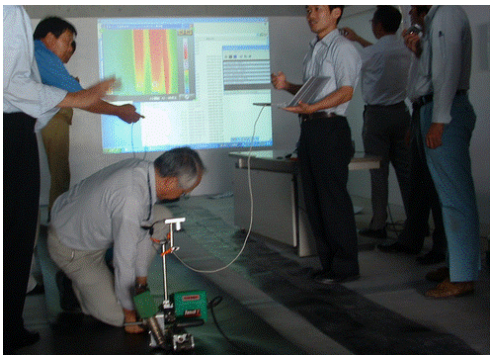

Fig.6 A scene of the experiment

3 RESULTS AND DISCUSSIONS

Figure 7 and Figure 8 are the thermal images that were taken when the sheets, which have groove scratch and gummed tape respectively, were welded together. On those images, the welding machine welded sheets from the top to bottom of the image. In figure 7, the temperature of the faulty area, where a groove scratch of 2mm width and 1mm depth was made on the upper sheet, was apparently higher than the normal area. Figure 8 shows a thermal image of faulty seams caused by affixed gummed tape. Unlike the case of the faulty seam with scratch, temperature in the faulty area was lower than the normal area, since the heat capacity of the part where the gummed tape located increased, and the heat transfer in boundary surface decreased.

Figure 9 shows the surface temperature on the welded seam recorded in the monitoring frames and figure 10 shows the highest and the lowest values of the recorded surface temperature. Arrows in figure 10 indicate the location of the faulty area on the seam. Apparent peaks can be seen on the highest surface temperature at SU1-SU3 where

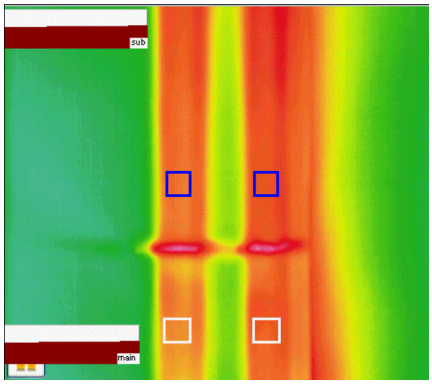

Fig.7 Thermal image of a seam with scratches

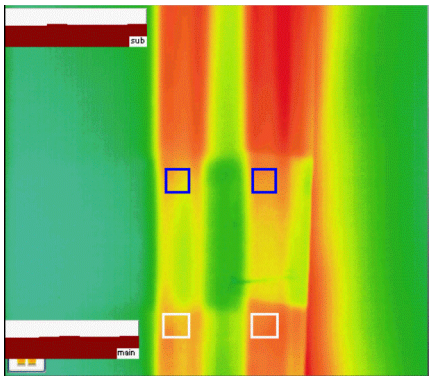

Fig.8 Thermal image of a seam with gummed tape

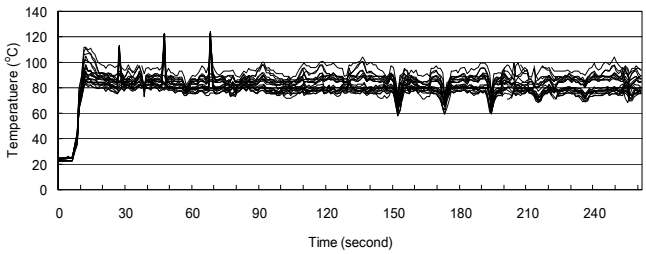

Fig.9 Surface temperature on the welded seam recorded at pixels in the monitoring frames

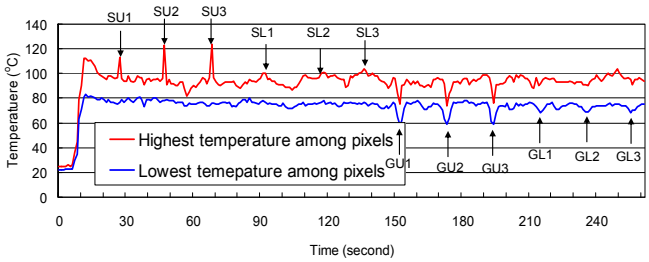

Fig.10 Highest and lowest surface temperature among the pixels in the monitoring frames

groove scratches were made on the upper sheets. Temperature at SL1-SL3 where scratches were made on the lower sheets did not change so much. The lowest temperature in figure 10 sharply decreased at GU1-GU3 where the gummed tapes were affixed on the upper sheet, and it slightly decreased at GL1-GL3 where the gummed tapes were affixed on the lower sheet.

Table 1 is shows the result of the TGI and Air Pressure testing to detect the faulty area on the welded seam. On the normal area of the seam, the average temperature of all pixels (μ_{AT}) was 83°C. The average of the highest temperature among pixels (μ_{HT}) was 94°C and the average of the lowest temperature among pixels (μ_{LT}) was 75°C. In order to find faulty areas on the seam, we used $\mu_{HT}+3\sigma_{HT}$ as a threshold temperature for the detection of the faults caused by groove scratch and $\mu_{LT}-3\sigma_{LT}$ as a threshold for the detection of faults caused by gummed tape. Results indicated that the scratches made on the upper sheet were detected by TGI while the ones made on the lower sheet could not be detected. According to the result by the APT, all of those faulty areas with scratch were not detected since melted HDPE flowed into the groove, the air did not leak out. All the faulty areas with gummed tape were detected by both the TGI and the APT.

4 CONCLUSION

This study describes a TGI method for the detection of faulty seams using a thermo graphic device. TGI enables the real-time inspection of the seams while sheets are welded together by heat-welding machine. And the recorded video of the thermal image and temperature data saved as csv files can be used as the evidence of the inspection. However, there are remaining subjects that should be improved such as the size and the location of the monitoring frames, setting of the thresholds, etc. Moreover, this method must be tested in a real liner sheet construction site.

Table1. Result of the fault detection test by the Thermo graph Inspection (TGI) and Air Pressure Testing (APT)

Seam	Item		Temp (°C)	Threshold for TGI*	Detection	
					TGI*	APT**
Normal area	Average of all pixels (μ_{AT})		83	-	-	-
	Average of the highest temperature among pixels (μ_{HT})		94	-	-	-
	Standard diviation of HT (σ_{HT})		3.5			
	Average of the lowest temperature among pixels (μ_{LT})		75	-	-	-
	Standard diviation of LT (σ_{LT})		2.0			
Faulty area	Groove scratch	SU1	113	$\mu_{HT}+3\sigma_{HT}$ =104.5°C	D	ND
		SU2	123		D	ND
		SU3	124		D	ND
		SL1	100		ND	ND
		SL2	99		ND	ND
		SL3	99		ND	ND
	Gummed tape	GU1	58	$\mu_{LT}-3\sigma_{LT}$ =69.0°C	D	D
		GU2	59		D	D
		GU3	59		D	D
		GL1	67		D	D
		GL2	68		D	D
		GL3	67		D	D

*TGI : Thermo Graph Inspection
**APT: Air Pressure Testing

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