proceedings

Abstract

Fundamental study on estimation of texture layer structure using infrared thermography †

Kana Miyamoto [1], Naruki Hosoda [1], Daiki Shiozawa [1*], Takahide Sakagami [1], Yuki Tomotaki [2], Norimitsu Kamiyama [2] and Mari Inoue [3]

[1] Department of Mechanical Engineering, Kobe University, Kobe 657-8501, Japan
[2] TEIJIN FRONTIER CO., LTD., Osaka 530-8605, Japan
[3] Department of Human Development and Environment, Kobe University, Kobe 657-8501, Japan
* Correspondence: shiozawa@mech.kobe-u.ac.jp
† Presented at the 18th International Workshop on Advanced Infrared Technology & Applications, 15–19 September 2025.

Abstract: Fiber-to-fiber recycling must be promoted to achieve sustainability in the textile industry. Mixed fiber materials cause significant issues in recycling, making accurate sorting essential for recycling. Garments may contain internal materials called interlinings, which are wrapped in the outer fabric and are not visible from the garment surface. This study proposes a non-destructive method for detecting interlinings in garments using active infrared (IR) thermography. Numerical simulations showed that the presence, thickness, and material of the interlining affected the cooling behavior. Fourier analysis of the surface temperature curves revealed that an increased interlining thickness leads to slower cooling and a greater phase lag, enabling the identification of interlining characteristics from thermal responses.

Keywords: Nondestructive inspection; infrared thermography; Numerical simulation; Texture

Citation: To be added by editorial staff during production.

Academic Editor: Firstname Lastname

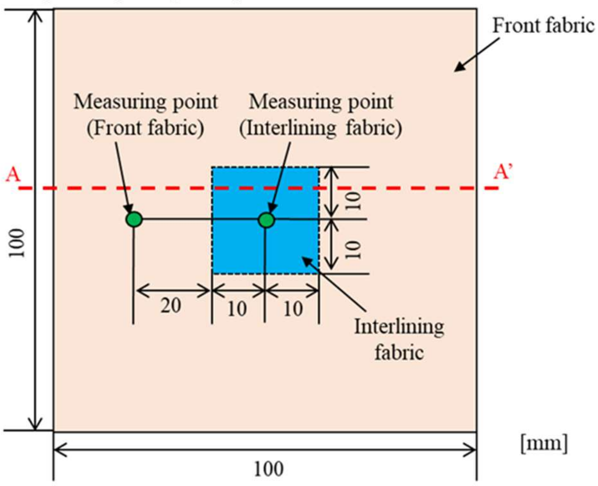
Published: date

1. Introduction

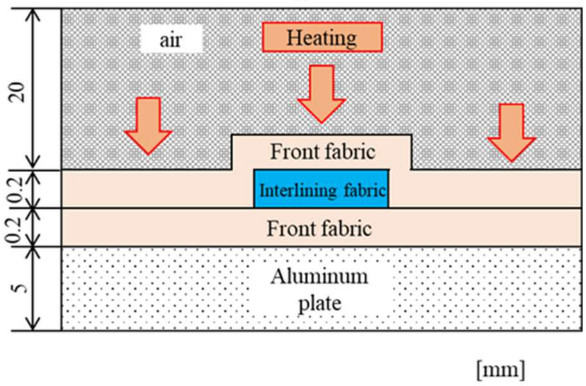
Currently, approximately 780,000 tons of clothing are given away annually by households and businesses in Japan, of which only 15.6% is recycled and 19.6% is reused; the remaining 64.8%, equivalent to 510,000 tons, is discarded [1]. Most current textile recycling practices are downgrade processes, such as converting used fibers into industrial wiping cloths or reclaimed fibers, which results in degraded material quality. In contrast, "fiber-to-fiber recycling", in which used textile products are recycled into new textile products, accounts for less than 1% of all recycling efforts [2]. Promoting fiber-to-fiber recycling is crucial for achieving sustainability in the textile industry. One of the key barriers to implementing fiber-to-fiber recycling is the sorting process that precedes it. When different materials are mixed during the recycling process, the quality of the remanufactured material is significantly reduced. Garments are made from various fiber materials. During the recycling process, fibers must be sorted by type. Garments may contain internal materials called interlinings, especially in areas such as the collar and sleeves. These interlinings provide structural support to help maintain the shape of the garment. The interlinings are wrapped in the outer fabric and are not visible from the surface. Therefore, it is necessary to destroy the garment to identify the interlinings for sorting purposes. A non-destructive and efficient inspection method is required because this sorting method is inefficient and costly. Infrared thermography is a non-destructive testing method that measures the surface temperature distribution of a target using infrared cameras and detects internal defects or structural variations based on thermal differences. This study investigates the feasibility of applying active infrared thermography for the material identification of interlinings in textile products using numerical simulations of transient heat conduction. When the surface of a fabric is heated and heat conduction occurs in the direction of the garment's thickness, the difference in heat conduction due to interlining appears in the temperature fluctuations on the outer surface. A numerical analysis of unsteady heat conduction was conducted, and a fast Fourier transform (FFT) was applied to investigate the effect of interlining on surface temperature fluctuations, specifically focusing on their presence, thickness, and material type.

2. Measuring Principal

This study employed active infrared thermography to estimate the internal structures. Active infrared thermography is a nondestructive testing method that evaluates internal defects or damage by detecting temperature variations caused by thermal excitation applied to a material. This technique enables wide-area inspection and is particularly suitable for the analysis of multilayer textile structures. The analytical model comprised a textile structure with an interlining between two outer fabrics, as illustrated in Fig. 1. The upper surface of the outer fabric was heated, and the surface temperature was recorded. When the interlining has a lower thermal conductivity than the outer fabric, the surface temperature is expected to cool more slowly in regions where the interlining is present. To quantitatively evaluate the difference in cooling behavior between the presence and absence of interlining, FFT analysis was applied to the time-series surface temperature data. The effect of interlining characteristics on the surface temperature response was examined by analyzing the phases.



(a) Top side



(b) Cross-section (A-A′)

Fig. 1 Numerical analysis model

3. Analysis Conditions

An unsteady heat conduction analysis was conducted using the commercial finite element software Marc. The dimensions of the interlining, outer fabric, aluminum plate, and air layer were all set to 100 mm × 100 mm. The thicknesses of the outer fabric, the aluminum plate, and air layer were 0.2, 5, and 20 mm, respectively. The initial temperature of each node was set to 20°C. A uniform heat flux was applied to simulate pulse heating, starting at t = 0 s and lasting for 0.008 s with a total heat input of 3000 W. The total simulation time was set to 15 s with a time step of 0.008 s. The interlining materials were modeled as either cotton or polyethylene terephthalate (PET), whereas the outer fabric was modeled as PET. The FFT analysis was performed on the surface temperature curve from 0.016 s (third step, immediately after the heating pulse ended) to 15 s (1875th step).

4. Analysis Results

Figure 2 shows the surface temperature curves for different interlining thicknesses and material types. Surface cooling was slower in regions with interlining than in those without interlining for both cotton and PET interlining materials. This is due to the time required for heat to transfer through thicker interlining materials. The phase differences at a frequency of 0.067 Hz between the regions with and without interlining, obtained through the FFT analysis, are shown in Figure 3. Figure 3 shows that as the thickness of the interlining increased, the phase lag also increased. The phase differences for the interlining materials at a fixed thickness of 0.4 mm are shown in Fig. 4. Figure 4 indicates that cotton interlining causes a larger phase lag compared to PET. A slower surface cooling corresponds to a larger phase delay in the FFT analysis. These results confirm that the presence, thickness, and material of the interlining can be identified based on features extracted from the surface temperature curves, such as the phase lag.

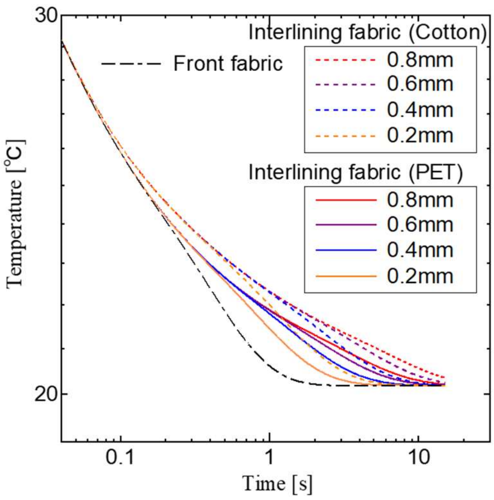


Fig. 2 Temperature curve for different material and thickness of interlining fabric in simulation

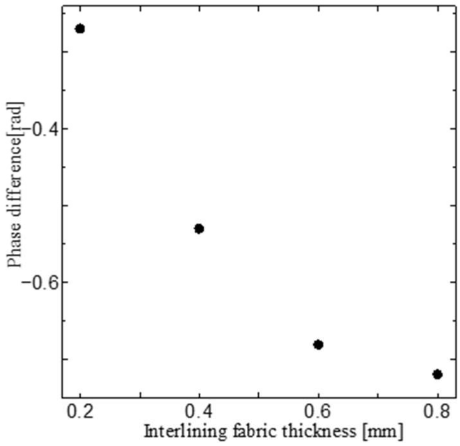


Fig.3 Phase difference for different thickness of interlining fabric

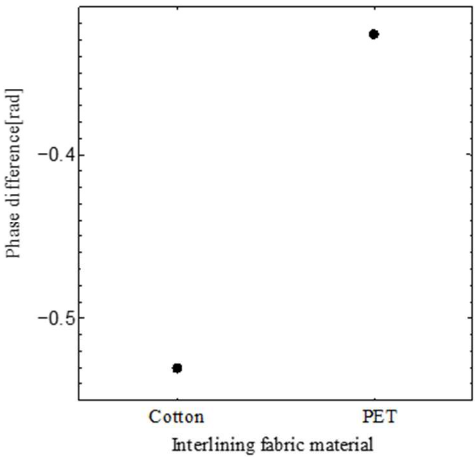


Fig.4 Phase difference for different material of interlining fabric

5. Conclusion

As a fundamental study on interlining detection in garments using active infrared thermography, numerical simulations of transient heat conduction were performed. The results showed that regions with interlining exhibited slower surface cooling than those without interlining. Additionally, the differences in interlining thickness and material affected the surface cooling behavior. These differences were reflected in the phase values obtained through the FFT analysis of the temperature curves. These results confirm that active thermography can non-destructively detect the presence, thickness, and material of interlinings in textile products.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions is required. The following statements should be used "Conceptualization, Kana Miyamoto ; methodology, investigation, writing, data curation, —original draft preparation Naruki Hosoda ; investigation, Daiki Shiozawa ; software writing—review and editing, Takahide Sakagami ; project administration, writing—review and editing, Yuki Tomotaki, Norimitsu Kamiyama and Mari Inoue ; resources, writing—review and editing

Funding: This research was funded by the New Energy and Industrial Technology Development Organization (NEDO), "Research and Development of Sorting and Separation Technology for Recycling Textile Products.

Data Availability Statement: Data will be made available upon request.

References

1. Ministry of the Environment, Fashion and Environment: https://www.meti.go.jp/shingikai/mono_info_service/resource_recycling/pdf/002_02_00.pdf (accessed 2025-5-25)
2. NEDO, Development of Technology to Establish a Resource Recycling System for Textile Products: https://www.meti.go.jp/shingikai/mono_info_service/resource_recycling/pdf/001_05_00.pdf (accessed 2025-5-25)