INTERNATIONAL SCIENTIFIC CONFERENCE
20-22 November 2025, GABROVO

USE OF IMAGE ANALYSIS IN THICKNESS PREDICTION OF THERMOFORMED PACKAGING

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Abstract
In this study, Image Analysis was used as a verification tool in thickness prediction of thermoformed packages. First, the thickness distribution of thermoformed packages in three different colours was obtained experimentally. Then, thickness variation was estimated using the light transmittance of thermoformed packages. Particularly, the light-transmitting side walls of the packaging were taken into consideration, and the thickness of the side walls was predicted. ImageJ, a Java-based, open-source Image Processing software, was used to generate thickness predictions. Predicted and obtained thickness values were compared to each other. Thickness values predicted by ImageJ, showed good agreement with the experimental results.
Keywords: image analysis, thermoforming, thickness, prediction, light transmittance, ImageJ.

INTRODUCTION

Thermoforming is a process in which a thermoplastic sheet is heated until it becomes soft and pliable, then shaped over or into a mould by applying vacuum, pressure, or mechanical means, and finally cooled so it retains the new form. After cooling, the excess material is trimmed away, leaving the desired three-dimensional part. Thermoforming is extensively used in the packaging industry to manufacture food safe trays, clamshells and blister packs that combine product protection with visual appeal. It also serves the automotive and aerospace sectors. In healthcare and consumer goods industries the process produces sterile instrument housings, device enclosures and custom display inserts thanks to its design flexibility and relatively low tooling cost. Thermoforming also supports high quality, custom packaging solutions across food, pharmaceutical and electronics sectors thanks to its flexibility in sheet material processing and mould design [1].

There is a large volume of published studies describing the role of thermoforming process parameters on final thermoformed package's condition. Thickness distribution is one of the most critical parameters that influences the strength of the package. Thickness distribution directly affects the appearance of the package. Also, thickness variation of the package, determines the shelf life of the food [2-7].

Determination of thickness distribution in thermoformed packaging is typically performed using destructive testing methods. Destructive testing methods can reduce the efficiency of mass production and lead to waste of time and thermoformed packaging. A considerable amount of literature has been published on alternative methods for determination of thickness distribution in thermoformed packages. Image Analysis (IA), X-ray computed tomography, digital image correlation (DIC), magnetic field-testing principles, and ultrasonic thickness measurement are some

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of these methods. However, studies on non-destructive determination of thickness distribution are lacking in the main literature. Especially, non-destructive thickness determination via Image Analysis is rarely reported [8-14].

ImageJ is one of the most well-known software platforms for image processing. Distances and areas can be determined with user-defined options within the software. Utilizing ImageJ image processing tools, engineers can examine cross sectional images of thermoformed sheets to estimate wall thickness variations across complex geometries. This approach enables a non-contact, full field measurement technique that complements simulation results and helps identify thinning zones before final production [15].

In this study, thermoformed food packages in three different colours (yellow, pink, red), were selected and thickness distribution on the side wall of packages was obtained experimentally. Thickness variation on the side wall of the packages were predicted via Image Analysis using Image j software. Predicted and obtained thicknesses were compared to each other. Estimated thickness variations show very good agreement with obtained results.

MATERIAL AND METHOD

An amorphous thermoplastic, Polystyrene was used for thermoforming of food packages in yellow, pink and red colours. A quarter of a package sample was cut and taken for the measurements. 20 Measuring points were selected on the sidewall of the food packages. The measurement points were selected on a straight line starting from the base radius of the sample and extending to the radius at the top. Figure 1 shows the measuring points in detail. A thickness comparator (precision: 0.001 mm, Akyol LYK 5318, Turkey) was used in measuring operations. Also, dimensions of the thermoformed food package is given in Figure 2.

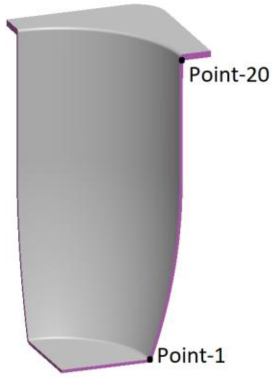

Fig. 1. *Measuring points selected on the side wall of the sample.*

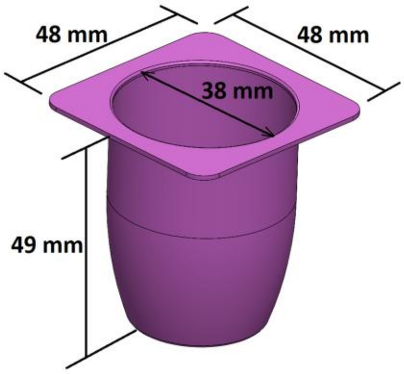

Fig. 2. *Outer dimensions of the thermoformed food package.*

Measurements were repeated with three samples for each colour of package. Thickness distribution for a package was obtained as an average of thickness variations in three samples. Thickness distribution of each sample was examined using graphical method via MS Excel. Additionally, thicknesses were estimated using IA at the selected points. Results were analysed comparatively.

EXPERIMENTAL PROCEDURE

Thickness distributions were obtained for 20 points along a predetermined path(from point-1 to point 20). For yellow, pink and red food packages, measuring procedure was repeated three times using different test samples. Average thickness value was determined for each measuring point.

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IMAGE ANALYSIS

Image Analysis is a basic tool which is used for recognizing, distinguishing, and quantifying diverse types of images in grayscale or colour [16]. In this study, light transmittance of a thermoformed food package was utilized to achieve thickness distribution estimation. Specifically, three food packages in yellow, pink and red colours, were selected. Effect of thermoformed food package's colour on thickness estimation via IA using ImageJ, was investigated.

Kırklareli University, Mechanical Engineering laboratory was used to record images for IA. Images were tried to be recorded under daylight, because daylight can provide more than 10 000 lux illuminance levels. Figure 3 shows the schematic IA set up.

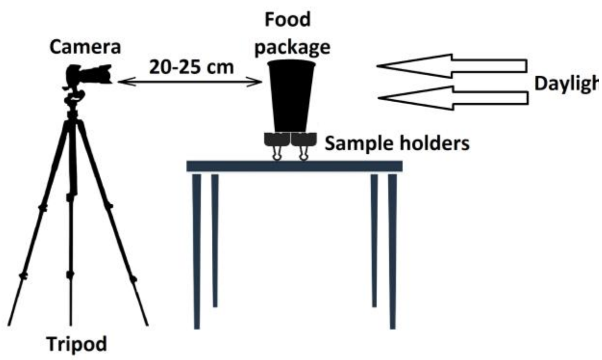

Fig. 3. *Schematic illustration of Image Analysis set up.*

The packages used in the study are made of translucent material that allows light to pass through. In front of the daylight, light coloured, and bright regions represent lower thickness, dark coloured regions represent higher thickness. When recorded sidewall images are converted into gray-scale images, Pixels in black colour means 0, while pixels in white colour are 255. Using Imagej software, recorded sidewall images were examined, and thicknesses were estimated for 20 measuring points.

In order to determine thickness variation in the thermoformed sidewall surfaces, grayscale-optical analysis was performed in ImageJ software. The digital sidewall images taken under daylight illumination were first translated into 8-bit grayscale mode in order to obtain pixel intensity values ranging from 0 (black) to 255 (white). Darker pixel regions in the images correspond to thicker wall sections due to reduced light transmission and light pixel regions indicate thinner wall sections.

A linear reference line was established at the lower corner of the sidewall and then replicated along the direction of the x-axis to cover the entire measurement length. The total length of the study area that is unique in every package was split into 19 equal lengths, providing 20 measurement lines providing pixel spacing values between approximately 88 pixels and 100 pixels depending on the shape of the study package. Every measurement line was defined as a vertical line ROI over the sidewall height, and precisely positioned with the ROI Manager → Duplicate and Translate functions of ImageJ. All ROIs were kept active (not permanently drawn) to keep them measurable. The resulting gray-value profiles were exported and statistically averaged. Profile-based thickness estimates were compared against the experimentally determined values of thickness obtained using the mechanical comparator to identify the accuracy and consistency of the non-destructive optical prediction method.

RESULTS AND DISCUSSIONS

The Gray-scale intensity profile of the sidewall region demonstrates the relationship between the optical transmission of light and local thickness distribution of the thermoformed package. Thicker regions are depicted by lower intensity values (dark areas) due to the reduced capability of the light to pass through the polymer material, while thinner wall sections with higher transmittance of light are depicted by peak intensity. As can be seen from Figure 4, the profile shows a

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stepped decrease in intensity, representing progressive thickening from top region to the base radius of the part. This is representative of material behaviour to be expected in thermoforming, where thinning at top edges due to stretching and compression towards corner and flange causes wall thickening.

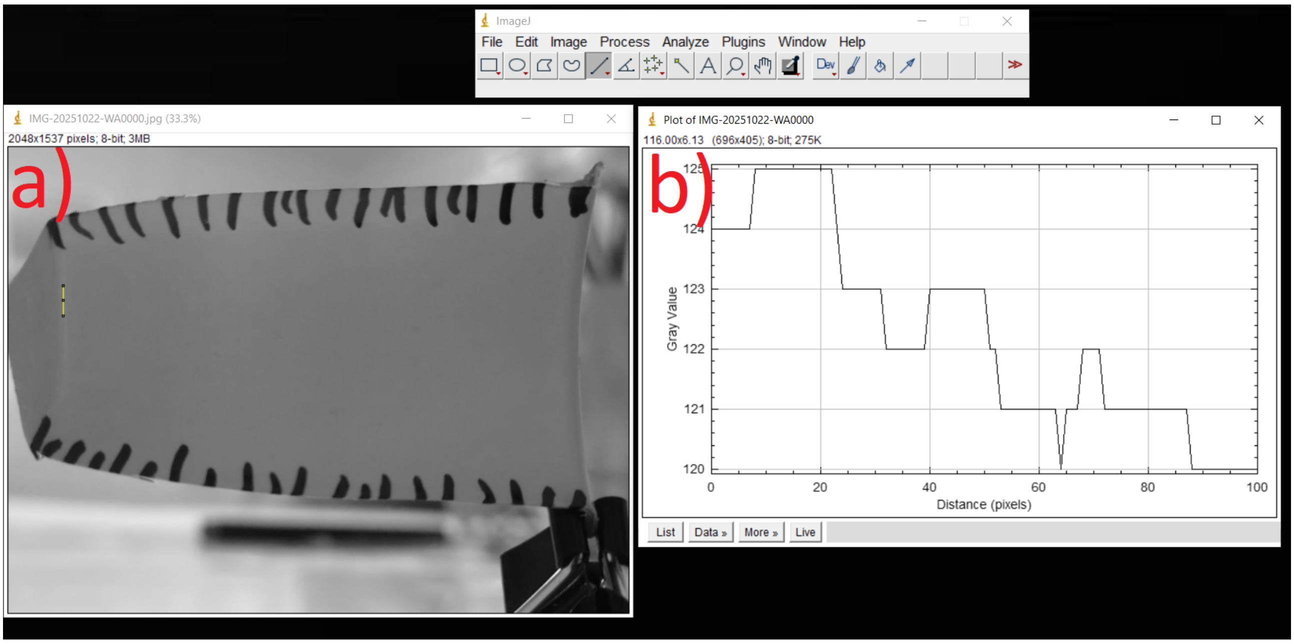

Fig. 4. (a) Selected ROI location on the thermoformed packaging sidewall, (b) the corresponding gray-scale intensity profile extracted using ImageJ.

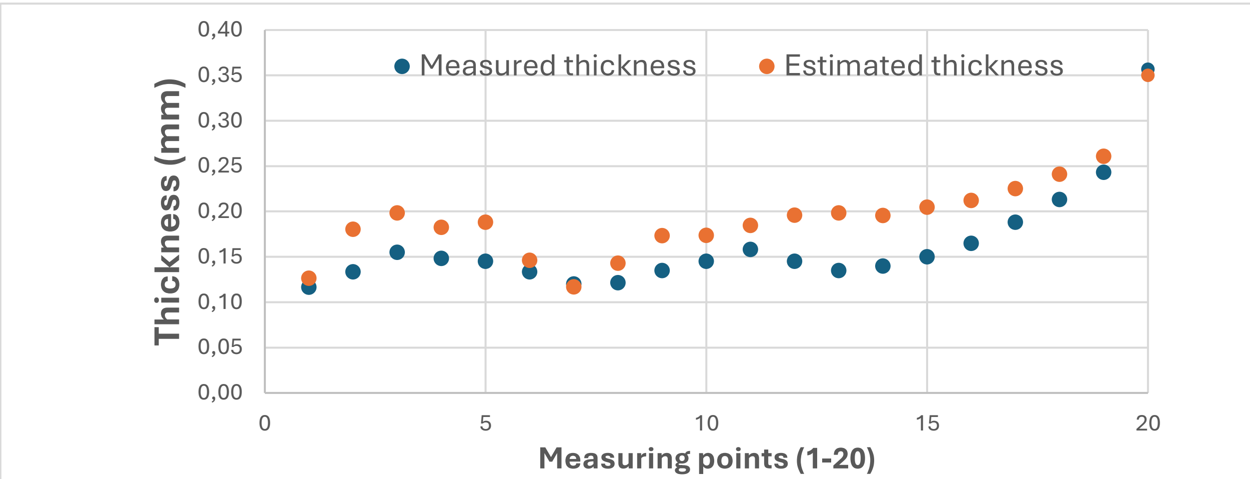

Fig. 5. *Measured and estimated thickness distributions along 20 measurement points on the sidewall of the* ***red thermoformed package****.*

"UNITECH – SELECTED PAPERS" vol. 2025
Published by Technical University of Gabrovo
ISSN 2603-378X

doi: www.doi.org/10.70456/..........................

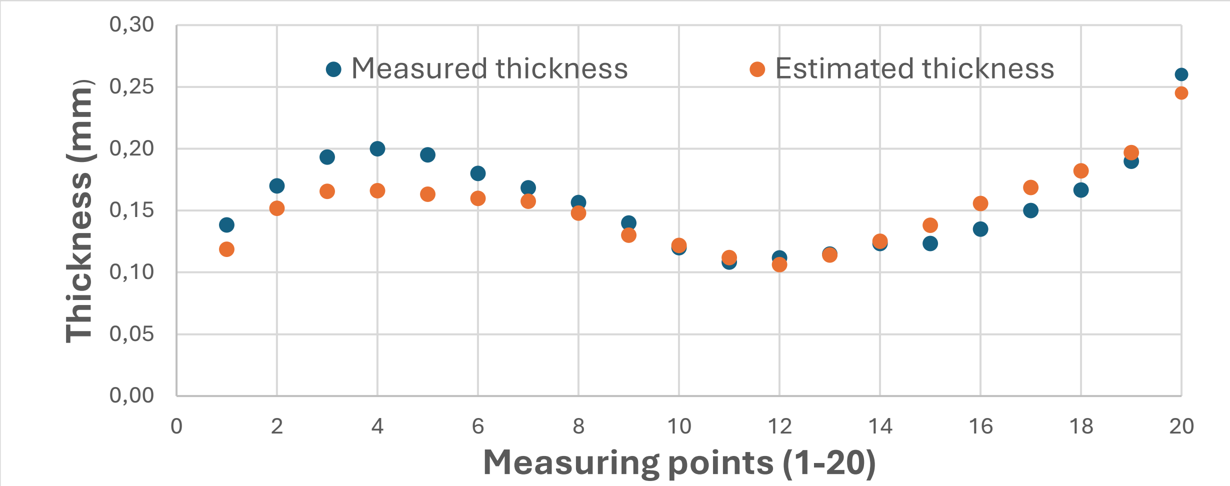

Fig. 6. *Measured and estimated thickness distributions along 20 measurement points on the sidewall of the* ***pink thermoformed package****.*

For the red thermoformed package, both measured and estimated thickness distributions show a smooth build-up from the top section towards the radius of the package base as depicted in Figure 5. Grayscale-based estimates perfectly capture the same trend as well as local points of thinning and thickening on the sidewall. Although the estimated values are optimistically biased relative to the measured thickness at every point except a very few, this is because the red colour transmits less light. The red package results therefore conclude that the optical method does a correct relative thickness assessment but requires a minor calibration correction to match with absolute values.

The thickness distribution in pink thermoformed package has its maximum near the lower region, declines in the middle section, and rises towards the top section as seen in Figure 6. The approximated curve is a good approximation of this spatial variation with minimal difference, exhibiting an excellent linear relationship between grayscale intensity and actual thickness for this material.

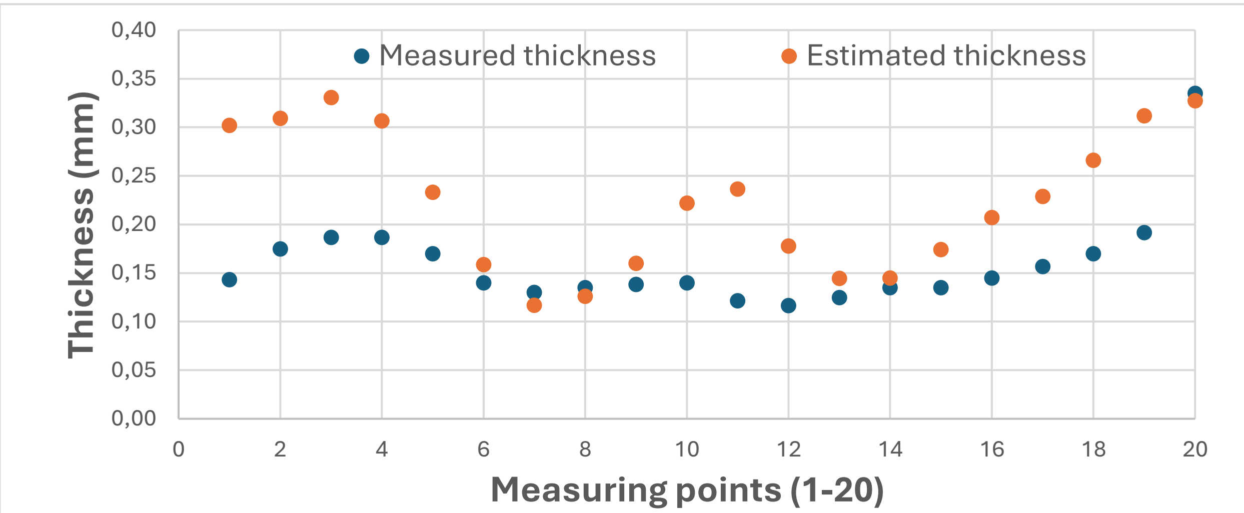

Fig. 7. *Measured and estimated thickness distributions along 20 measurement points on the sidewall of the* ***yellow thermoformed package****.*

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Considering the results of the yellow package, the estimated thickness values show more noticeable overprediction, particularly at measurement points 1–7 and 12–16 as shown in Figure 7. The discrepancies are likely caused by greater optical transmittance of yellow polymer material, so it is prone to grayscale sensitivity. Yet, the estimated thickness remains with a comparable curvature to the measured distribution, showing that the spatial trend can be identified effectively. Therefore, the yellow package results emphasize the necessity of colour-dependent calibration in order to achieve correct thickness estimation.

CONCLUSION

In the current study, the thickness distribution for thermoformed food packaging made from polystyrene was measured experimentally and with the aid of a non-destructive image-based estimation technique. ImageJ software was utilized to convert the acquired sidewall photographs to grayscale mode, and pixel intensity change in space was utilized for estimating the wall thickness at twenty selected points of measurement. Three different coloured packages (red, yellow, and pink) were employed in the study to test the effects of material colour on accuracy in thickness prediction.

The results showed that the calculated thickness values closely resembled the experimentally determined distributions for all packages, successfully capturing local thinning and thickening regions caused by the thermoforming process. Small quantitative differences were found despite colour-dependent light transmittance variations, and these can be minimized by simply carrying out a colour-specific calibration procedure. ImageJ-based grayscale analysis was therefore proved to be an effective and feasible non-destructive thickness measurement technique.

In conclusion, the proposed approach facilitates rapid evaluation of wall thickness uniformity without the requirement of destructive testing, and it is significantly useful for quality control and optimization applications in industrial thermoforming processes.

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