Master thesis: Thickness metrology of thin aluminium foil with FEM implementation

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1 Introduction

Today is the thickness of the aluminium foil at Tetra Pak® only described with the average thickness. It is calculated by weighing a predefined area (1 dm^2) of the aluminium foil and by using the formula

$$t_{avg} = \frac{Mass}{Density * Area}.$$

In FE-simulations are the average thickness used together with perfectly smooth surfaces. The purpose of this thesis has been to experimentally measure the surface topography on both sides of the foil, hence a thickness variation can be determined. That information has then been used to create models for FE-simulation. The simulations were performed to see if the topographies influence the localized necking that occurs while subjected to tension.

2 Work flow

During this thesis was a work flow developed that transferred the aqcuired surface topographies of aluminium foil into FE-models. The work flow is visualized in Figure 1. The different steps are:

- Find suitable equipment for topography measurements.
- Perform the measurements, create a digital reconstruction of the foil surface.
- Use parameters and color ranges to quantify and get a clear visualization of the surface topographies.
- Transform the surface topographies into a mesh.
- Use the mesh in FE-simulations

3 Measurements

It was chosen to perform the measurements with the Alicona InfiniteFocus microscope at LTH. It is a optical light microscope based on the focus variation technique. By taking images of the specimen's surface at different height the software of the microscope can determine the height of each individual measure point. When every measure point has been assigned a height a surface topography has been created. The measurements were divided into two rounds; the first round contained measurements on one surface of the aluminium foil while the second round contained rotational measurements.

Several comparisons were made during the work of this thesis. The first comparison was investigating the difference between the two sides of the aluminium foil. During the final step of production two foils are rolled together, called the doubling process. This process make the two surfaces to have different characteristics. The sides of the two foils that is in contact with the work rollers is called the bright side. The two sides of the foils that is in contact with each other are called the matt sides.

The comparison between the two sides showed that the matt side is coarser then the bright side of the foil. The arithmetic height of the surface, expressed by the Sa parameter, is 50 % higher for the matt side, 224 versus 337 nm for the bright and the matt side, respectively. The bright side has a clear feature of rolling lines which can be seen in Figure 2 as lines from the top to the bottom of the image. The rolling lines shows up as clear directions in the gradient images. Surprisingly does the matt side have a main direction as well visible in its gradient image. The direction of the matt side is perpendicular to the direction of the rolling lines on the bright side. In Figure 3 the matt side is shown, the direction would be from the left to the right side of the image.

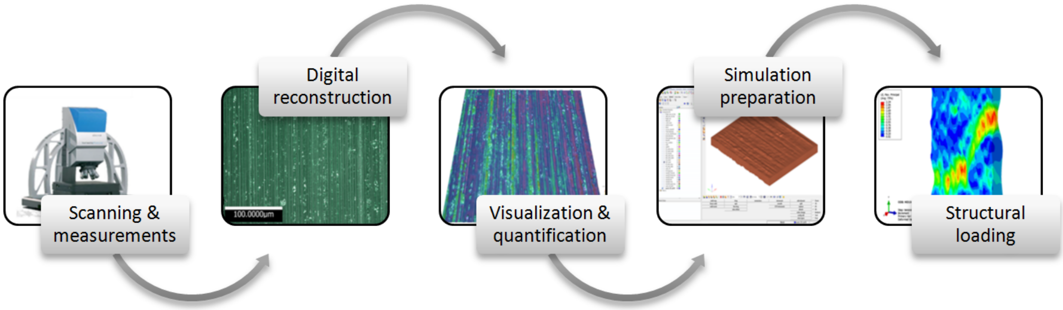


Figure 1: Work flow created and used during this thesis

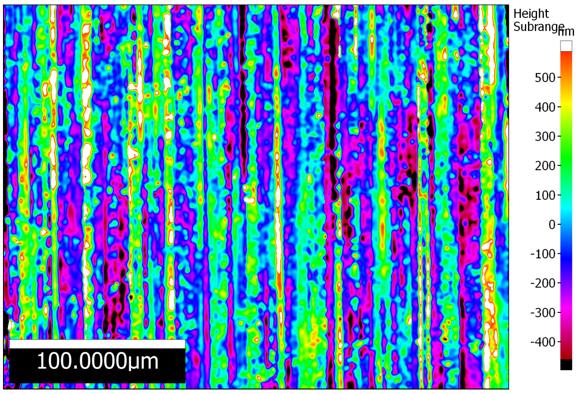


Figure 2: Bright side of the foil with height range

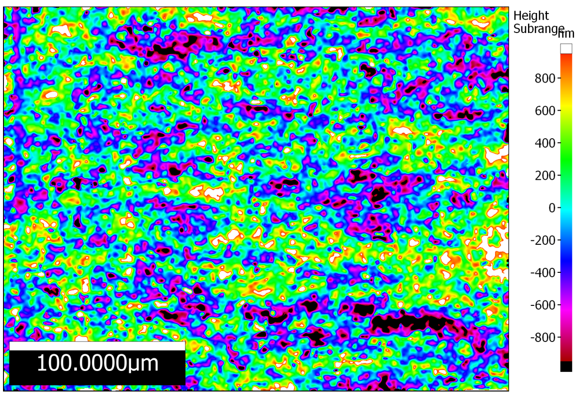


Figure 3: Matt side of the foil with height range

The rotational measurements were never successful, therefore was no true thickness variation achieved. Causes and possible fixes is presented in the discussion.

4 FE-simulations

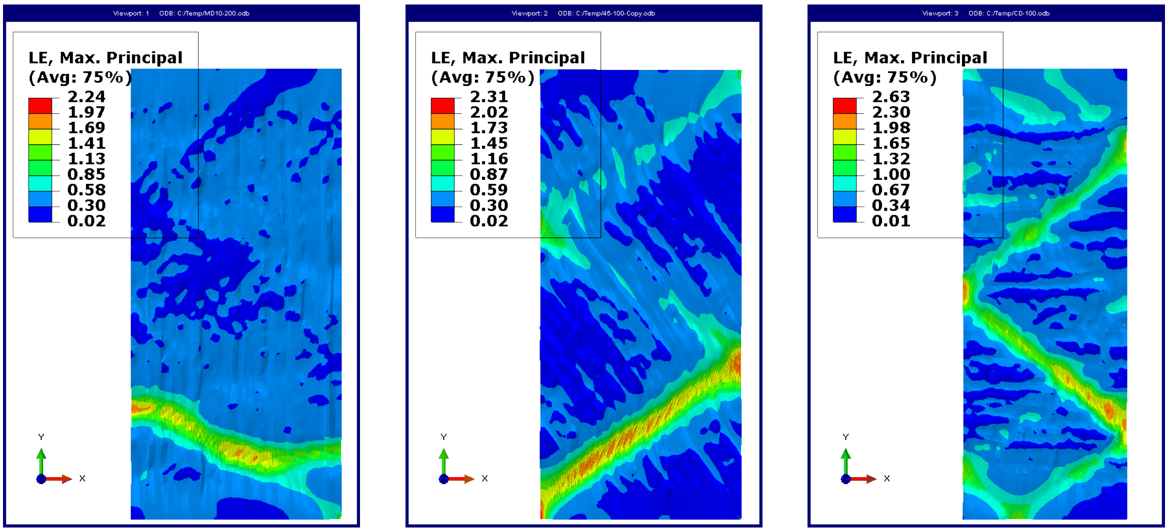
Into the simulation models were two one sided measurements used. The models mesh had a size of 100x100 μm and were set up so they would resemble a little piece of a large tensile test. Three models were used for simulations; they were subjected to tension loading in machine direction (MD), 45 degree direction (45°) and cross direction (CD). The reason for the directions in these models is to coincide with earlier work at Tetra Pak [1]

When the correct conditions for the models were achieved all models showed clear localized necks. The strain values were all along the neck well over a 100 % and the maximum was well over 200 %. The neck of the MD model looks like it is following the surface topography of the matt side with its curvy shape, see Figure 4a. The necks in 45° and CD models formed in a zigzag pattern, see Figure 4b and Figure 4c.

5 Discussion

The localized neck in the MD model have a curvy form. Close up images of a failure in a physical tensile tests reveal that the failure do not occur in a straight line, but in a more curvy way. It might be that the surface topography influences the failure path for tension in MD direction. In the two other models the necks formed at an angle of approximately 35° from the horizontal axes. Those necks are probably due to slip band formations and not the topography.

Only a few samples for each variant were tested. Therefore is the results maybe a little bit uncertain. The Sa parameters presented in the results are each one an



(a) Tension in MD (b) Tension in 45° (c) Tension in CD

Figure 4: FE-models at last equilibrium

average of only five measurements done on each side. For some other comparisons made in this thesis only one measurement was done on each side. This means that the statistical significance is low for the measurement results.

That no rotational measurements were successful was due to the hard light conditions. The foil is very reflective which means that either did the foil reflect all light straight back into the microscope or away from the microscope. The microscope could not handle the big differences in light during one measurement. A possible fix is to measure smaller areas of the foil an stitch the measurements together with help of software. However, no such licence was available for that particular software during this thesis.

The work flow developed during this thesis will hopefully continue to be used after the end of this thesis. It can lead to more advanced FE-models at Tetra Pak. Not only regarding the aluminium foil, this work flow can possibly also be used on the paper board.

References

[1] B. Käck; C. Malmberg. Aluminium foil at multiple length scales, mechanical tests and numerical simulations in abaqus, 2015.