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Investigation of mechanical properties for Non-Homogeneous by image tracking method

Rahmawati Munir [a,*], Handika Dany Rahmayanti [a], Nadya Amalia [a], Fisca Dian Utami [a], Sparisoma Viridi [b], Mikrajuddin Abdullah [a]

[a] Material and Electronic Physics Laboratory, Faculty of Mathematics and Natural Science, Bandung Institute of Technology, Jl. Ganesha 10, Bandung 40132, Indonesia
[b] Nuclear Physics and Biophysics Laboratory, Faculty of Mathematics and Natural Science, Bandung Institute of Technology, Jl. Ganesha 10, Bandung 40132, Indonesia

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A B S T R A C T

We have investigated new approach to predict mechanical properties for non-homogeneous materials. The investigation used copy paper 100 gsm as sampling object using image tracking method and based on bending of cantilever slender beam. The copy paper 100 gsm was shaped on non-homogeneous geometris than placing it with curvature angle variations (0°, 45° and 90°). We snapshot the copy paper sample using digital camera later tracked the coordinates at several points after divided the beam image into 16 segments. Futhermore, we calculated Modulus Young using elasticity equation for non-homogeneous beam. The results presented show that it is possible to obtain a good Modulus Young value due to approach Modulus Young value obtained by direct measurement using tensile strength device. This method is expected to become a reference for developing Modulus Young estimation for non-homogeneous geometry materials without direct contact.

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1. Introduction

Today, the elasticity materials become tremendously important [1]. Numerous applications of the use mechanical properties of materials, such as supporting of industrial progress in civil buildings, electronics and the food industry, for example in the design of food packaging resistant to environmental changes such as temperature [2]. Many characterization methods have been used to understand the properties of materials. At the present, a method of characterization the elasticity of materials is image processing [3,4]. This method can be done directly or with the results of the recording, simple but can provide enough information. In measurement technologies, image processing has become the most important to design instrument. The Scanning Electron Microscope (SEM), the Transmission Electron Microscope (TEM) and the Atomic Force Microscope (AFM) are measurement methods based on image processing [5,6,7]. All information in the form of material structure, morphology and atomic interactions in materials was presented using this method. The use of these methods requires high costs. This limitation has become a factor to take into account when carrying out measurements with a simple method requiring lower costs. Therefore, a number of alternative measurement methods that have been developed are also based on image processing to replace these measurement methods. In this research, the image processing method was developed on the folding material by applying the cantilever beam principle. The bending profile of the cantilever beam was taken using a camera and then processed using a calculation method to obtain the modulus of elasticity. The dependence of the elasticity on the density parameters and the cross-section of the cantilever beam becomes the basis for the development of this measurement method. Therefore, section and density data based on the bending profile image of each material obtained can be used to calculate the modulus of elasticity.

In this study, we focus on the principle of cantilever beams that depend on physical parameters such as the bending moment of one's own weight. Each sample is divided into N segments of the length of each a. The first segment starts at the free end and ends at the linked end. The bending angles of each segment differ because they have different bending moments in the sample. The

* Corresponding author.
E-mail addresses: rahma.mipaunmul@gmail.com, rahmawati@fmipa.unmul.ac.id (R. Munir).

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bending angle of the jth segment is θj, which corresponds to equation (1) [8].

$$\theta_j = \theta_{j-1} - \frac{a^3 g}{Y_j I_j} \sum_{i=1}^{j-1} \left(\sum_{k=1}^{i} \lambda_k \right) \cos\theta_i \tag{1}$$

Where I_j is the moment area, Y_i is the modulus of elasticity, λ_j is the density of the long unity in the jth segment and g is the acceleration of Earth's gravity. Equation (1) can also be written as

$$Y_j = -\frac{a^3 g}{I_j(\theta_j - \theta_{j-1})} \sum_{i=1}^{j-1} \left(\sum_{i=1}^{j-1} \lambda_k \right) \cos\theta_i \tag{2}$$

The modulus of elasticity calculation for homogeneous material using equation (2). However, to calculate the modulus of elasticity for non– homogeneous material, for example the shape of the variable width trapezoid if it is divided into N segments at the tip of the sample, equation (2) does not meet. Therefore, as a function of physical parameters in the form of a variable sample width, equation (2) becomes

$$Y_{\boldsymbol{j}} \approx -\frac{a^3 g \lambda}{I_j(\theta_j - \theta_{j-1})} \sum_{i=1}^{j-1} i\cos\theta_i \tag{3}$$

In simulation process, using equation (2) to calculate homogeneous samples and equation (3) for non-homogeneous samples. The modulus of elasticity scattered throughout the sample is N. The data distribution is approximated by the Gaussian function to obtain the modulus of elasticity between Y and Y + dY, satisfying the equation

$$\boldsymbol{\Psi}(\boldsymbol{Y})\boldsymbol{dY} = \frac{1}{\sqrt{2\boldsymbol{\pi\sigma}^2}} \exp\left[-\frac{(\boldsymbol{Y} - \bar{Y})^2}{2\sigma^2} \right] \boldsymbol{dY} \tag{4}$$

Then, we fit scattered data using Equation (4) to obtain the average elastic modulus as well as the standard deviation σ [8].

2. Experimental

This research based on the calculation of Modulus Young for homogeneous material and non-homogeneous materials. The whole calculation was done using equation (2) for homogeneous material and equation (3) for non-homogeneous materials. At the preparation stage, the sample was prepared in the form of rectangular paper with two variations, namely plain and colored (pilox coated). Next, a trapezoidal paper sample was prepared with the same treatment as a rectangular sample. The final sample was prepared in a rectangular shape but the density changes throughout the sample by coating it with a pilox. Furthermore, a simple experimental method design was made as shown in Fig. 1. The images result from the experimental was processed image tracking using video tracker software version 4.94 (open source). The calculation of experimental data was carried out with the help of VBA for Excel 2016. The development of new methods in measuring the modulus of material elasticity was carried out aimed at simulating various materials that could be measured under various circumstances. The simple design of the elastic modulus measurement method is shown in Fig. 1.

Experiment was conducted by varying the angle for each sample then taking picture using a digital camera. Futhermore, the data processing with image tracking, fitting equations and simulation to obtain elasticity modulus.

3. Results and discussion

The development of the measurement methods for modulus of elasticity, physical parameters which become the object of measurement are density of the material, geometrical shape and curvature angle of each observed material. Physical parameters are measured, calculated and observed through experiments with a simple design without any touch to the material being measured. A series of treatments starts from sample preparation, sample photography, Image Tracking, simulation until a modulus elasticity value was obtained that close to the value of the results of the tensile test using a tool. Sample preparation in the form of paper (100 gsm) was measured by varying physical parameters in the form of geometric shapes, angles of curvature and density of materials. Measurement of elastic modulus for rectangular (assumed to be homogeneous material) samples. Assumptions that rectangular shaped samples were homogeneous have been reported by Makela and Soren Ostlund, 2003. Measurements were conducted by varying the curvature angles of 0° and 45°. Assumptions that rectangular shaped samples were homogeneous were reported by Makela and Soren Ostlund, 2003. Further measurements were made by varying the curvature angles of 0° and 45°. Measurement of elastic modulus for trapezoid-shaped samples (assumed to be non-homogeneous material). The change widths throughout the sample form the basis that the geometric shape non homogeneous. Because the width of the sample is one of the parameters in the calculation.

The simulation was performed using a total length of A4 paper L = 0.16 m. The length of the segment was determined as a = 0.0005 m for all length values. Four teta N angles, namely 0°, 45°, and 90°, were reviewed for each length value. Measurement of elastic modulus for trapezoid-shaped samples (assumed to be

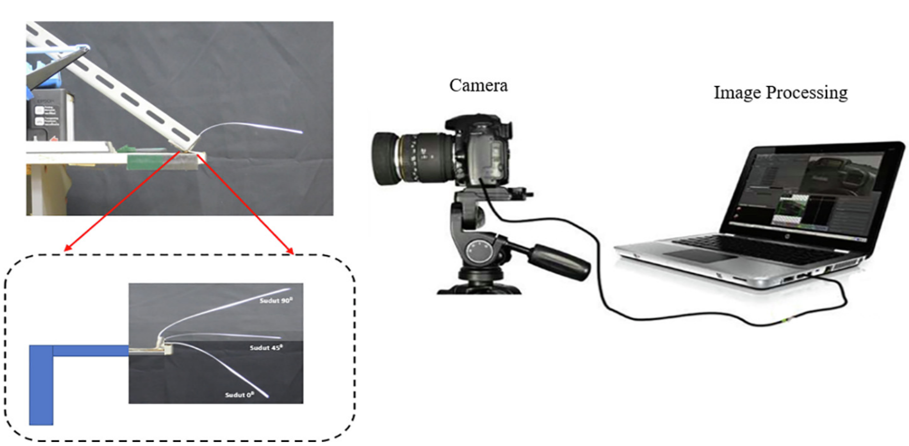

Fig. 1. Illustration of a simple experiment measurement of materials elasticity modulus.

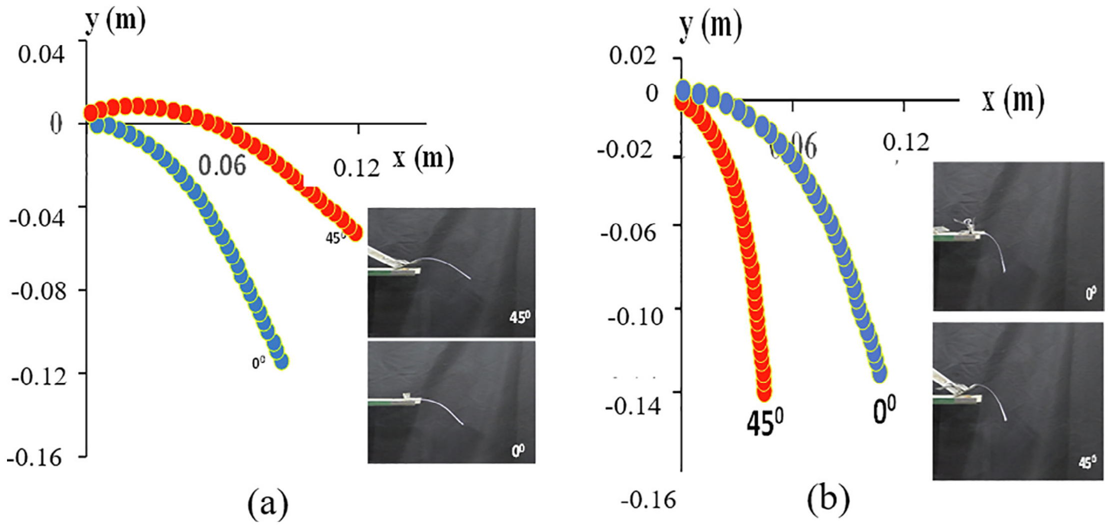

Fig. 3.1. Comparison of the image deflection profile results through image tracking using a video tracker. (a) Rectangular-shaped samples and (b) Trapezoid-shaped samples.

non homogeneous material). Fig. 3.1 shows the results of image tracking using a video tracker by performing mass track points on each segment that has been divided into 16 segments. The mass points of each segment consist of two points so that the mass points obtained in the sample image were 32 coordinates points on the x-y axis. The deflection profile of the sample was rectangular (Fig. 3.1(a)) and the sample is trapezoidal (Fig. 3.1(b) shows the difference in curvature. It was estimated that the influence of the geometric shape of the different samples. For trapezoid-shaped samples, the free end was long side and the bound end was shortest side.

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Young modulus tensile testing or elastic modulus (E) was performed to confirm the results obtained through the Image Tracking method which simulated with the simulation results (Table 1). We also testing the results using tensile strength measurement in the Physics Laboratory of the Bandung Institute of Technology using the 10KN Universal Testing. From the data in Table 1, we can confirm that the proposed method can well estimate the elastic modulus of materials where the difference of calculation and measurement almost the same. This result is showen in samples with 45° curvature angles.

The calculation results for plain paper samples are 2.42 GPa (curvature angle: 0°); 2.18 GPa (curvature angle: 45°) and 2.32 GPa (curvature angle: 90°) close to value of direct measurement results approximately 1.4–2.1 GPa (see Table 1). We consider cantilever beam equation that used in this calculation according to conditions of material profile being measured its elasticity modulus. The material is sheets paper forming when one end is clamped and the other end is left dangling it will form a curved profile. For the papers coated pilox gave results that are not so close to value elasticity modulus by direct measurements but are still in the same orde (GPa). This case is due to coatings that are not evenly distributed throughout sample surface, involved the surface becomes rigid. Rigid material was difficult to track so cannot be calculated using image tracking method (curvature angle: 90° for paper coated by pilox). Based on this work, we assume that image tracking measurement method only applies to sheets material forming or materials that can be curved if one end is clamped and the other end is left dangling.

4. Conclusion

We have shown that Image Tracking method of bending cantilever beams using a series of procedures: tracking images, calculating bending angles, adjusting bending angles to polynomial functions, calculating elastic modulus in each segment using discrete equations of bending equilibrium for sample sheets, we can accurately estimate modulus material elasticity. By testing with three samples, the procedure was able to estimate elastic modulus with deviations from the measurement results of less than 10%. By investigating the bending of cantilevered material placed on the experimental table, we were able to obtain curvature through the results of sample shooting. From the curve shown in the previous section, we can get the elastic modulus value of each sample without having to contact directly at the time of measurement. To justify the estimation results, we also measure directly using tensile test equipment and obtain consistency between the calculated results and experimental observations. Finally, we also check the accuracy of estimates and are very confident that accuracy is acceptable. It is important to mention that this is the first attempt to estimate the value of the elastic modulus of the material based on bending cantilever beams with the simplest method.

CRediT authorship contribution statement

Rahmawati Munir: Conceptualization, Methodology. **Handika Dany Rahmayanti:** Data curation, Writing - original draft. **Nadya Amalia:** Formal analysis, Investigation. **Fisca Dian Utami:** Formal analysis. **Sparisoma Viridi:** Writing - review & editing. **Mikrajuddin Abdullah:** Supervision.

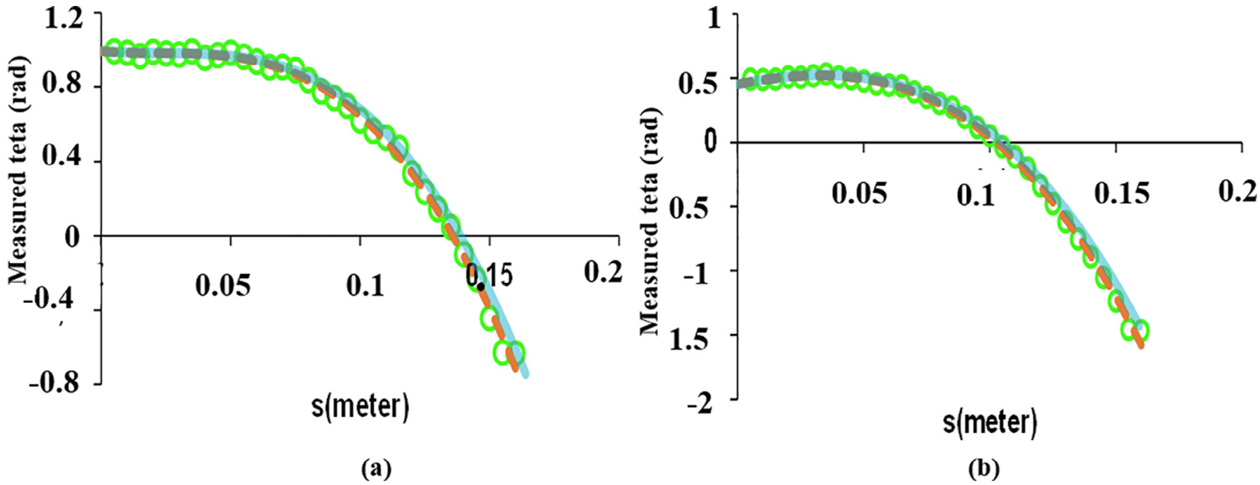

Fig. 3.2. Experimental data fitting graph (green colored round shape), theory (orange dashed line) and simulation (blue line) on rectangular sample. (a) Curvature angle 0° and (b) Curvature angle 45°. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

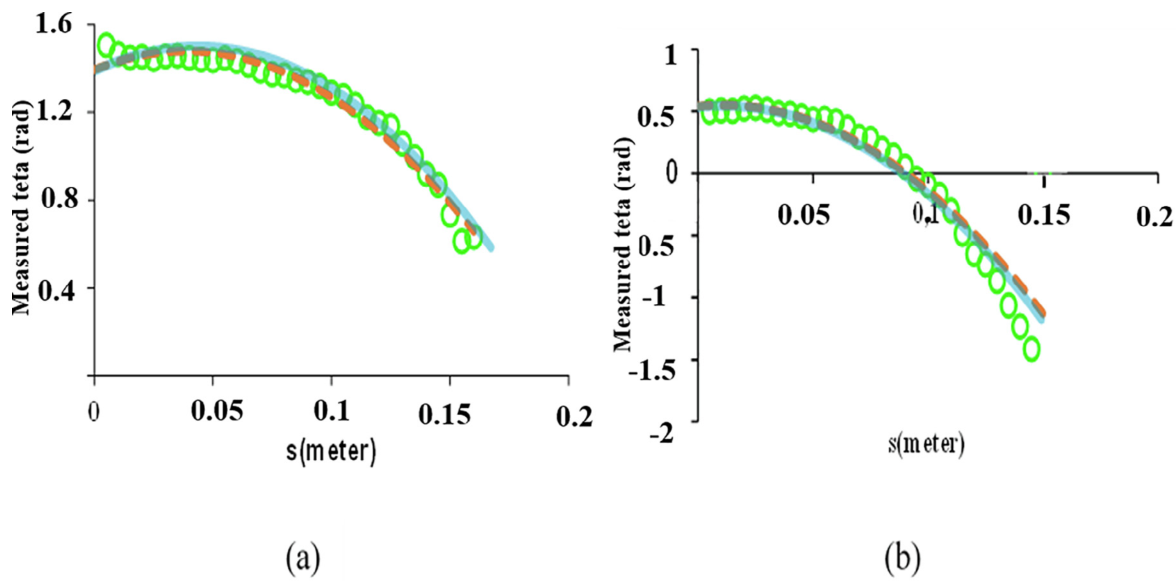

Fig. 3.3. Experimental data fitting graph (green colored round shape), theory (orange dotted line) and simulation (blue colored line) on trapezoid-shaped samples. (a) Curvature angle 0° and (b) Curvature angle 45° (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
The average values of elastic modulus obtained from calculation and direct measurement.

Angle	PlainPaper	Elasticity Modulus (GPa)		PiloxCoated	Elasticity Modulus (GPa)	
		Averaged calculated	Averaged measurement		Averaged calculated	Averaged measurement
0°		2.42	1.4–2.1		5.51	8.716
45°		2.18	1.4–2.1		7.59	8.716
90°		2.32	1.4–2.1		Not bend	-

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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