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Original Research Article

Development and Validation of a LEGO®-Based Texture Analyser for Tensile Testing Using Gelatine-Based Films with Different Glycerol Concentrations

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Abstract: Texture analysis is important for evaluating the mechanical properties of biobased plastics, providing valuable insights into their performance, durability, and suitability for various applications. However, conventional texture analysis is often expensive and complex, limiting its accessibility in academic research. Hence, this study employed a cost-effective alternative using a LEGO®-based texture analyser developed with Visual Studio Code, Arduino IDE, and MINDSTORMS EV3, adhering to ASTM D6882-12 (2012) to evaluate the mechanical properties of bio-based films, such as gelatine-based films. Gelatine was extracted from tilapia fish scales and incorporated with different concentrations of glycerol. It was indicated that increased glycerol content reduced tensile strength but enhanced elongation at break. The study concluded that the implementation of the LEGO®-based texture analyser was compatible with the conventional texture analyser for evaluating mechanical properties of gelatine-based films, showing a percentage deviation of 5.19% for tensile strength and 6.20% for elongation at break. The findings validated the LEGO®-based texture analyser as a cost-effective and efficient alternative for mechanical testing of biobased plastics, making it a promising option for small-scale academic research on biobased plastics.

Keywords: LEGO®-based texture analyser; gelatine-based film; tensile strength; elongation at break; glycerol; biobased plastic

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1. Introduction

Biopolymers have gained increasing attention as alternatives to synthetic polymers due to their potential to reduce environmental impact (Arif *et al.*, 2022; Babaremu *et al.*, 2023; Moshood *et al.*, 2022). Fish scales, a by-product of the fishing industry, offer a promising solution. The rising demand for non-mammalian gelatine for halal materials has

also increased interest in fish gelatine (Aziz *et al.*, 2024; Karim & Bhat, 2008). Fish scales should not have been neglected but utilised efficiently across various sectors. However, despite the growing interest in eco-friendly materials, bioplastic production remained low, which was 0.6% of global plastic production in 2019, mainly due to high material and production costs (Negrete-Bolagay & Guerrero, 2024).

Evaluating the mechanical properties of biopolymers during development was crucial (Petroudy, 2016). These properties were essential in determining the material's suitability for applications such as packaging, biomedical products, and other eco-friendly uses (Perera *et al.*, 2023). However, the limited understanding of fish scale gelatine's mechanical behaviour remains a challenge. Even though conventional texture analysers can provide highly accurate measurements, they were often too expensive and complex for small laboratories or educational institutions (Hinge *et al.*, 2021). This has restricted accessibility for small-scale industries and researchers in conducting mechanical testing and comprehensive material characterisation.

Recently, a low-cost or open-source microcontroller-based tensile tester has been explored. This offered an affordable alternative for basic mechanical characterisation (Nandy *et al.*, 2018). By utilising readily available materials, such as LEGO® components and compatible sensors, an alternative testing device can also be developed by the researchers without compromising fundamental texture analysis capabilities. The significant cost advantage is demonstrated by comparing the prices, where the LEGO® Mindstorm EV3 Core Set costs approximately RM 4,300 while the smallest texture analyser costs around RM 72, 000, showing a cost difference of around RM 68,000. Thus, highlighting the potential of the LEGO®-based system as a practical and economical approach for evaluating the tensile strength and elongation at break of fish scale gelatine films.

The focus of this research was to develop and evaluate a LEGO®-based texture analyser that can examine the tensile strength and break elongation of biopolymers derived from fish scale gelatine with respect to different plasticiser percentages and synthetic polymers. Then, the same samples were tested using both the LEGO®-based texture analyser and the conventional texture analyser during the mechanical properties test. This was to compare the results of both texture analysers and determine the ability of the LEGO®-based texture analyser as an alternative to the conventional texture analyser. So, the reliability of the LEGO®-based texture analyser can be determined as a viable alternative to the conventional texture analyser. Furthermore, the potential of the LEGO®-based system could

be optimised according to specific applications, utilising creativity and innovation to address scientific challenges from this initial study in the future (Hosseini *et al.*, 2020).

2. Materials and Methods

2.1. Extraction of Fish Scale Gelatine

The process based on AI-Temimi *et al.* (2021), Limpisophon *et al.* (2009), and Weng and Wu (2015) was used to extract gelatine from tilapia fish scales. To remove any remaining residue, dried fish scales were first cleaned with tap water. They were then soaked in 0.05 M sodium hydroxide (NaOH) and 25% methanol (Chemiz (M) Sdn. Bhd., Malaysia) at 10.0 °C in a scale-to-solution ratio of 1:4 (w/v). This was to eliminate the alkaline-soluble proteins and optimise the extraction process (Nurhayati *et al.*, 2021). After they were soaked overnight or for 24 h, they were washed with distilled water three times or more. The fish scales were demineralised by soaking them in a 0.05 M hydrochloric acid (HCl) (Chemiz (M) Sdn. Bhd., Malaysia) solution for approximately 2 h, with a scale to solution ratio of 1:5. The acid enhanced the swelling and change the crosslinks found in the collagen resulting in better hydrolysis and greater yield (Rather *et al.*, 2022). They were then rinsed with distilled water once more. The scales were heated to 80.0 °C for approximately an hour in distilled water. This was to destroy the hydrogen bonds to convert the gelatine to soluble gelatine (Binsi *et al.*, 2017). Next, they were centrifuged at 11,000 RPM for 30 min to obtain a clear supernatant fluid. Finally, the extracted fish gelatine was freeze-dried in the freeze dryer for 3 days and stored in a freezer. The gelatine yield was calculated from Equation 1 below (Kanwate & Kudre, 2022).

$$Gelatin\ Yield\ (\%) = \frac{Dry\ Weight\ of\ Gelatin(g)}{Dry\ Weight\ of\ Fish\ Waste\ Used(g)} \times 100 \quad (1)$$

2.2. Film Production

The solution casting followed a method used by Gonz'alez *et al.* (2016) and Azmi *et al.* (2024). About 2% (w/v) of the extracted fish scale gelatine made in 2.1 was combined with hot distilled water (60 °C). After that, the mixture was constantly agitated for half an hour. After the gelatine was completely dissolved, 15% (w/w of the gelatine) of glycerol (R & M Chemicals, Ever Gainful Enterprise) was added. To eliminate the air bubbles, the sonicator ultrasonic liquid processor was used to sonicate the solution for 10 min at 50 Hz (Azmi *et al.*, 2024). A 14 cm internal diameter Petri dish containing 45 mL of the solution

was used to hold the solution after it was cast into the plates. For two days, it was left to dry at room temperature. The film produced was then carefully peeled out from the Petri dish and stored in a sealed plastic film in an environment of 57% humidity at room temperature. With varying glycerol percentages of 25% and 35% (w/w of the gelatine), the process was repeated.

2.3. Mechanical Properties Test

Firstly, the film's thickness was measured using a Digimatic Micrometre Series 293, Mitutoyo, Japan. Five films with the same percentage were used during the test for both the conventional texture analyser and the LEGO-based texture analyser. The gelatine-based films and nylon were cut, referring to the standard shapes defined in ASTM D6882-12 (2012), which was also used for red algae bioplastic films (Machmud *et al.*, 2013). This was illustrated in Table 1 and Figure 1. As the thickness of the film was less than 1 mm, it was not suitable for ASTM D638-14 (2015). This cutting measurement was to ensure the break occurred right in the middle of the film specimen. The speed was set to 20 mm/min or 0.333 mm/s and was performed at room temperature (Machmud *et al.*, 2013).

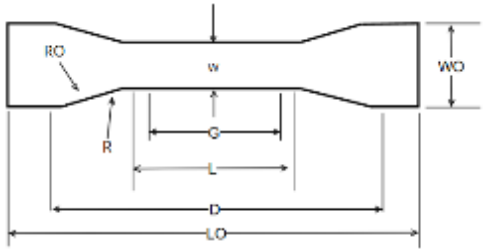


Figure 1. ASTM D6882-12 (2012) specimen cut guideline

Table 1. The dimensions of the films (Machmud *et al.*, 2013).

Section	Type IV Dimension (mm)
W - Width narrow section	6
L - Length narrow section	33
WO - Width Overall	19
G - Gage Length	25
LO - Length Overall	115
D - Distance between grippers	65
R - Radius of Fillet	15
RO - Outer Radius	15

The force (N) and deformation (mm) were recorded; thus, the calculation of the stress and strain applied to the films can be calculated to plot a graph of stress vs strain based on the Equations 2 and 3 below (U.S. Naval Academy, n.d.).

$$Strain = \frac{Extension}{Initial\ gauge\ length, LO} \quad (2)$$

$$Stress = \frac{Force}{Original\ Cross\ Sectional\ Area} \quad (3)$$

The tensile strength and elongation at break of the films were ascertained and recorded by applying the following formulas (Equations 4 and 5) to analyse the peak stress value on the stress vs. strain graph. (Petroudy, 2016).

$$Tensile\ Strength = \frac{Maximum\ Load\ Force}{Original\ Cross\ Sectional\ Area} \quad (4)$$

$$Elongation\ at\ Break = \frac{Change\ in\ Gauge\ Length}{Original\ Gauge\ Length} \times 100\% \quad (5)$$

2.4. Design of LEGO®-Based Texture Analyser

The LEGO®-based texture analyser was designed by considering the optimum and best support for the main components and parts during the test. The main components of the model can be referred to in Figure 2. Two LEGO® Technic linear actuators, a touch sensor and two large servo motors were applied to it. The loading and unloading of tension motion of the crosshead connected to a tensile specimen was related to linear progression and regression movements of the actuators (Talib *et al.*, 2019). The gripper was constructed using the LEGO® blocks. Electrical components, such as the Arduino board, HX711 amplifier, and load cell, were soldered together. Electrical components were neatly arranged on the base of the LEGO®. One of the grippers was attached to the load cell base, while the other was attached to both linear actuators. The EV3 bricks were positioned on the back of the tower structure. A space for the EV3 charger and another 4-connector wire was also considered during the development. The texture analyser dimension and component positions can be referred to and illustrated in Figure 3, Figure 4 and Table 2. The films that were used in the mechanical test of the LEGO®-based texture analyser followed the same guidelines stated in ASTM D6882-12 (2012). All findings and results from the specimen testing were recorded, providing insights into the performance of the LEGO®-based tensile testing apparatus.

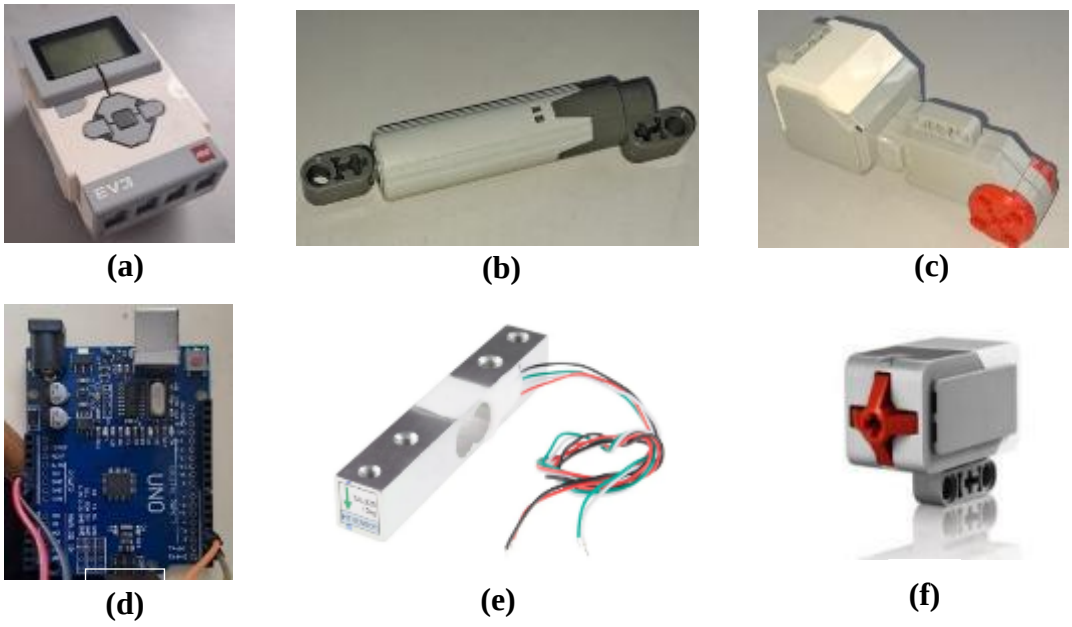


Figure 2. (a) The EV3 Programmable Brick, **(b)** linear actuator, **(c)** LEGO® motor, **(d)** Arduino board, **(e)** load cell and **(f)** touch sensor

Table 2. The dimensions of the LEGO®-based texture analyser developed

LEGO® – Based Texture Analyser Parts	Height (mm)	Width (mm)	Length (mm)
Tower	300	97	130
Load Cell Base	60	135	173
Motors' Gap	-	-	128
Gripper	10	58	117
Gripper's Gap	88	-	-
EV3 Brick Holder	60	55	104

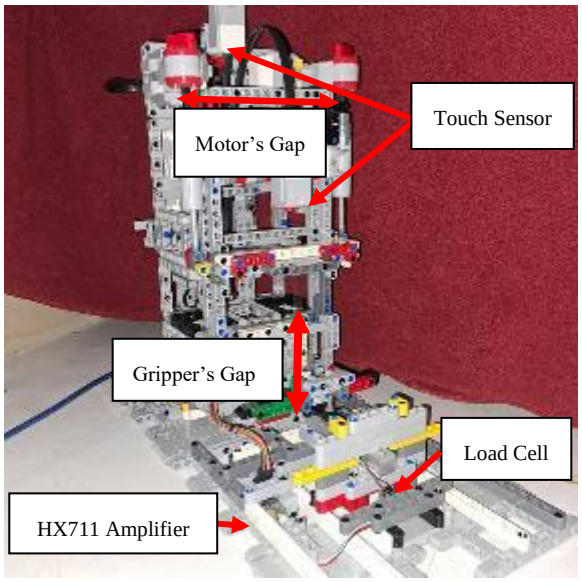


Figure 3. The position of small components on the model and the gap.

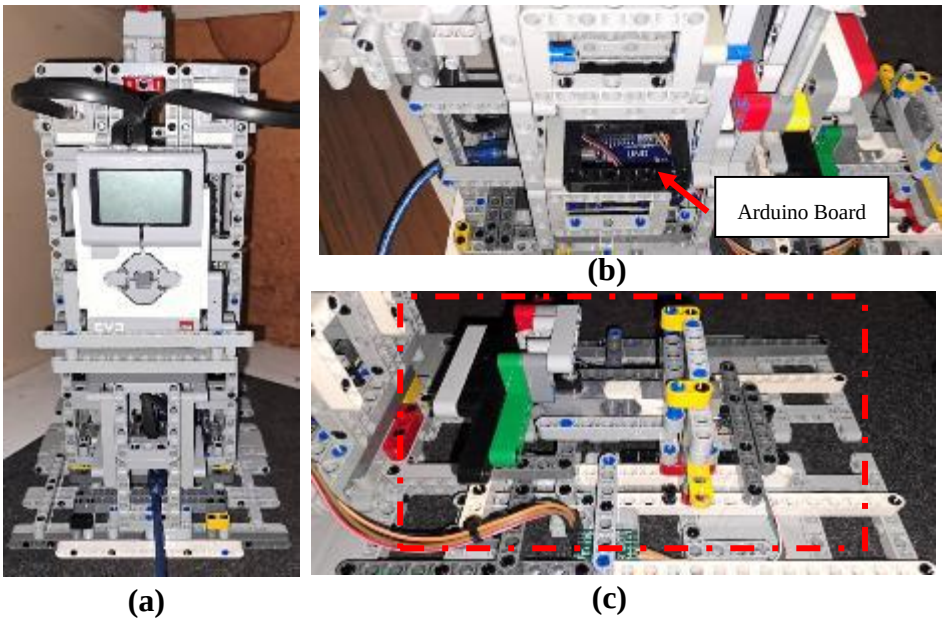


Figure 4. The position of **(a)** EV3 bricks and holder, **(b)** Arduino board, **(c)** load cell base

2.5. Code Development

2.5.1. Movement mechanism controller

The LEGO Mindstorms EV3, programmed using the Pybricks MicroPython library, was utilised to create an automated, sensor-controlled system. The EV3 Programmable Brick microcontroller was used to control the motor motions, and the open-source ev3dev operating system, which was based on Linux Debian, was used to program the Python language (version 3.5) (Talib *et al.*, 2019). The coding program applied the Python language through software called Visual Studio Code. Two large motors were connected to Port B and Port C, and two touch sensors were also connected to the EV3 Brick on Port S2 and Port S3.

The coding program began by initialising the EV3 Brick. The motors and the touch sensors were then initialised by defining their connected ports. Both motors were then activated simultaneously, with the left motor (L_motor) rotating in reverse at a speed of 240 degrees per second and the right motor (R_motor) rotating forward at the same speed. The speed set in the program was calculated based on Equation 6 below, referring to the linear displacement per rotation and the speed suggested in ASTM D6882-12 (2012), which was 20mm/min. The linear displacement per rotation was measured as 0.5mm before the test was conducted (Talib *et al.*, 2019).

$$Motor\ speed(°/s) = \frac{360 \times Linear\ speed\ during\ the\ test\ (mm/min)}{60 \times Linear\ displacement\ per\ rotation\ (mm)} \quad (6)$$

The motors continued running until the first touch sensor (ts1) was pressed, which indicated that the initial condition was met. The system awaited input from the second touch sensor (ts2). Once pressed, this sensor triggered the motors to restart in the opposite direction at a higher speed of 400 degrees per second. It lasted for 17 s and was managed using the sleep function to ensure it returned to its initial position. After the duration elapsed, the motors were stopped completely, marking the end of the test cycle.

2.5.2. Data receiver

To interact with the cell load amplifier, the HX711 library was introduced to the application. The calibration_factor, g_gravity, and m_mass were initialised to facilitate accurate measurements. Serial was used to initiate serial communication. The HX711 interface was initialised with the scale before starting (9600) to communicate data to the PC. start (SCK_PIN, DT_PIN). The scale was tared to set the current value to zero, and the calibration factor was applied to calibrate the system. The load cell readings were obtained using scale.get_units, which provided the weight in grams. This value was multiplied by g_gravity to calculate the force in newtons. The force was printed to the serial monitor using Serial.println. Delay (500) was used to apply a 500-ms delay in the loop to guarantee consistent data processing and collection.

2.5.3. Data collection and plot

A Python program was created to connect to the Arduino via the serial port and display the incoming force data in real time. The code was developed in Visual Studio Code and utilised the PySerial library to establish a connection on COM11 with a 1-s timeout. A 2-s pause was added at the start of the script to enable proper initialisation and synchronisation among the devices. The string data received from the Arduino was decoded and converted to a floating-point number, known as the raw force value. The timer was initialised to record the test duration as soon as the first data was received. So, elongation at break can be calculated. The force and time data were added to dynamic lists and visualised with matplotlib. animation libraries. The graph displayed force on the y-axis and time on the x-axis, with refresh rates of 100 ms. The real-time plotting capability allowed clear and immediate feedback on the force applied during the stretching of the film using the LEGO-based texture analyser.

2.6. Compatibility of LEGO®-based texture analyser

The results were analysed to obtain an understanding of LEGO®-based texture analyser compatibility in mechanical properties tests of materials. The conventional and

LEGO®-based texture analysers were used to compute and compare the mechanical property values for each specimen. The percentage deviation between the two analysers was also calculated to assess the compatibility of the LEGO®-based texture analyser. The formula used for the percentage deviation calculation was Equation 7:

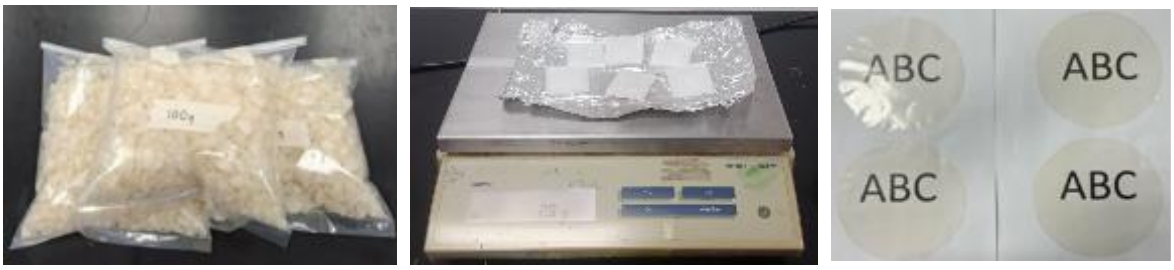
$$Percentage\ Deviation = \frac{V_{Standard} - V_{LEGO}}{V_{Standard}} \times 100\% \quad (7)$$

$V_{Standard}$ represents the value obtained from the conventional texture analyser. LEGO®-based results were deemed compatible if the percentage deviation fell within an acceptable range. Based on the average and range method, GAGE Repeatability and Reproducibility (GAGE R&R) is a widely applied calculation in industry to measure both repeatability and reproducibility. A deviation of 10% or less was considered excellent, while a deviation between 11% and 20% was regarded as adequate. Deviations ranging from 21% to 30% were classified as marginally acceptable, and any deviation greater than 30% was deemed unacceptable (McNeese, 2018). The observed differences were examined to determine potential reasons and limitations of the LEGO®-based texture analyser. If deviations exceed or fall below the acceptable range, analysis and improvements of the LEGO®-based texture analyser in the future will be required to align it to the standard. This enabled a better understanding of the strengths and limitations of the LEGO®-based texture analyser and provides insights into its potential as an alternative for testing mechanical properties.

3. Results and Discussions

3.1. Fish Scale Gelatine-based Film

The gelatine extraction yield was determined to evaluate the efficiency of the gelatine recovery process from fish scales. Following the extraction procedures, the dried gelatine's ultimate weight was determined and compared with the raw fish scales' initial weight. The extraction yield was calculated, and the result obtained was 6.2 ± 1.3%. This result falls between 4.6 ± 1.7% and 15.7 ± 0.2%, which was the range of research that applied gelatine made from leftover tilapia scales to antibiotic hydrogel pads (Wonganu, 2020). After the films had been cast, the surface texture was observed and tested. This was to verify the quality of the films before testing the mechanical properties of the films. For example, the oily or tacky films were rejected as they had failed to achieve the desired quality. Figure 5 shows some of the successful films produced during the study.



(a) (b) (c)

Figure 5. (a) The dry tilapia fish scales weighted (b) the dry gelatine weighted and (c) casted fish scale gelatine films.

3.2. Tensile Strength Test

Gelatine-based films' tensile strength was assessed using a traditional texture analyser. Figure 6 indicated that the highest tensile strength was recorded for nylon with 26.24 ± 4.47 MPa. This trend is explained by differences in their molecular structures. While PP and PE rely on weaker van der Waals forces, notably London dispersion forces, nylon shows significant hydrogen bonding between polymer chains (Hwang *et al.*, 2021; Li *et al.*, 2020; Gladysz & Chawla, 2015). The gelatine-based films demonstrated that an increased concentration of glycerol reduced their tensile strength. At the lowest glycerol content of 15%, the tensile strength was 23.81 ± 1.21 MPa. When the glycerol content increased to 25%, the tensile strength dropped to 20.24 ± 4.82 MPa. The highest glycerol content of 35% resulted in the lowest tensile strength, recorded at 17.19 ± 0.52 MPa.

These values were attributed to the plasticising effect of glycerol, which permeates and lowers the free volume within the polymer matrix by weakening hydrogen bonds and secondary interactions between gelatine chains. This interaction significantly affects the mechanical properties of the resulting film and disrupts the cohesive forces within the polymer (Giménez *et al.*, 2009; Azmi *et al.*, 2020; Karim *et al.*, 2022). Thus, reduced the strength of secondary bonding forces that normally hold polymer chains together (Karim *et al.*, 2021). In addition, excessive plasticiser (glycerol), also acted as a lubricant, reduced the frictional resistance of the polymer chains and lowered tensile strength. As a result, the film requires less force to stretch with increasing glycerol content.

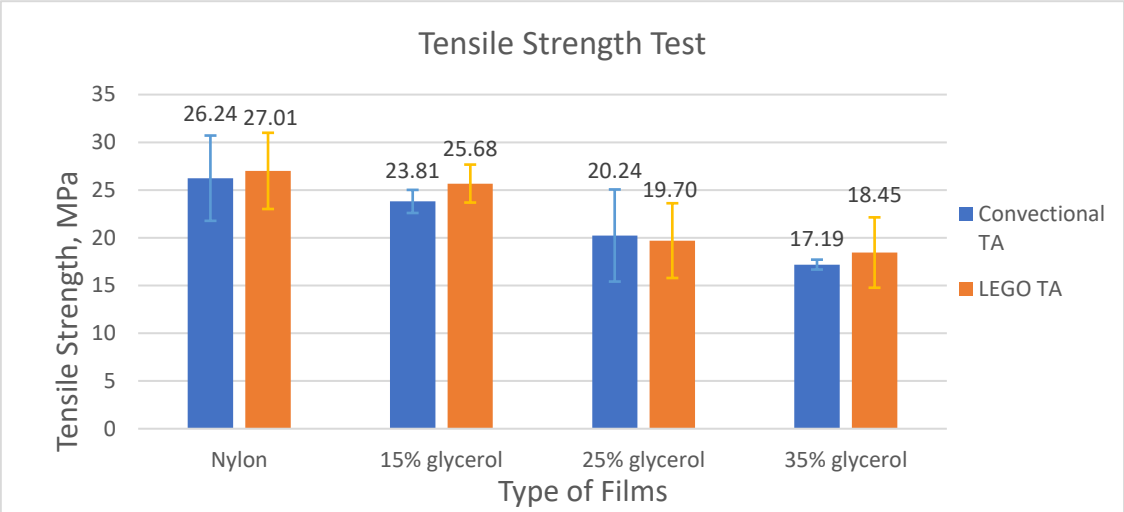


Figure 6. The tensile strength of the films tested on a conventional texture analyser and LEGO®-based Texture Analyser

The ability of the LEGO®-based texture analyser to conduct tensile strength tests has also been evaluated. The force value obtained was converted to the tensile strength using Equation 3. The value of the tensile strength acquired for the Nylon, 15%, 25% and 35% glycerol gelatine-based films were 27.01 ± 3.99 MPa, 25.68 ± 1.98 MPa, 19.70± 3.91 MPa and 18.45 ± 3.69 MPa, respectively. Based on the values obtained from the conventional texture analyser and LEGO®-based texture analyser, the percentage deviation of the test was calculated. The result showed a 5.19% deviation between the texture analysers. This was obtained after each sample deviation percentage was averaged.

3.3. Elongation at Break Test

A material's ductility and flexibility were indicated by its elongation at break. For gelatine-based films, the incorporation of glycerol significantly influenced their behaviour. Figure 7 indicated that the films showed greater elongation at break and became more elastic as the glycerol content rose. This was proven by the measured elongation values, where at 15% glycerol, the elongation at break was 22.42 ± 4.11%, increasing to 50.91 ± 4.02% at 25% glycerol concentration, and 85.15 ± 4.11% at 35% glycerol concentration. Besides, nylon with 54.55 ± 17.74% elongation at break recorded almost a similar value to the 25% glycerol gelatine-based film. This can be explained by the presence of strong hydrogen bonds restricting chain movement in nylon (Hwang *et al.*, 2021).

In gelatine-based film, glycerol reduced the intermolecular attraction between gelatine chains, which enhanced the chain mobility to make it easily deform under stress. Therefore, the stretchability and elasticity of the gelatine-based film can be increased.

Besides, a high glycerol content attracted and retained more water molecules due to its hygroscopic nature. This softened the films and increased their flexibility even more (Karim *et al.*, 2022; Gómez-Estaca *et al.*, 2009). Without it, the film structure is too rigid to allow deformation, leading to early breakage under tension and the lowest value of elongation at break (Wang *et al.*, 2025). Consequently, films with higher glycerol content were able to stretch further before failure.

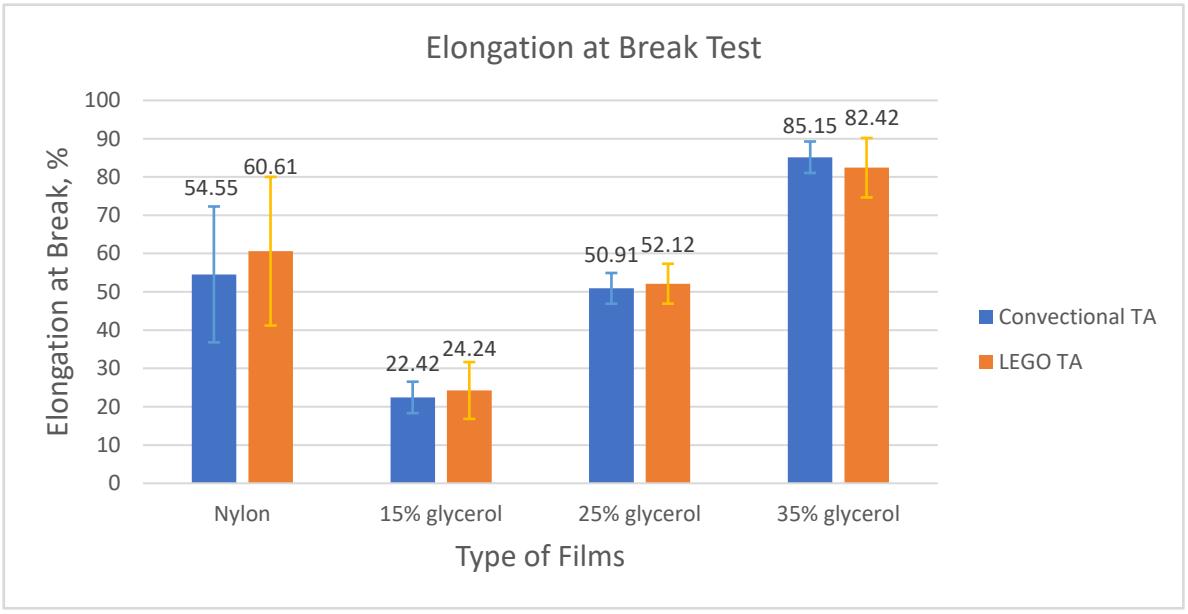
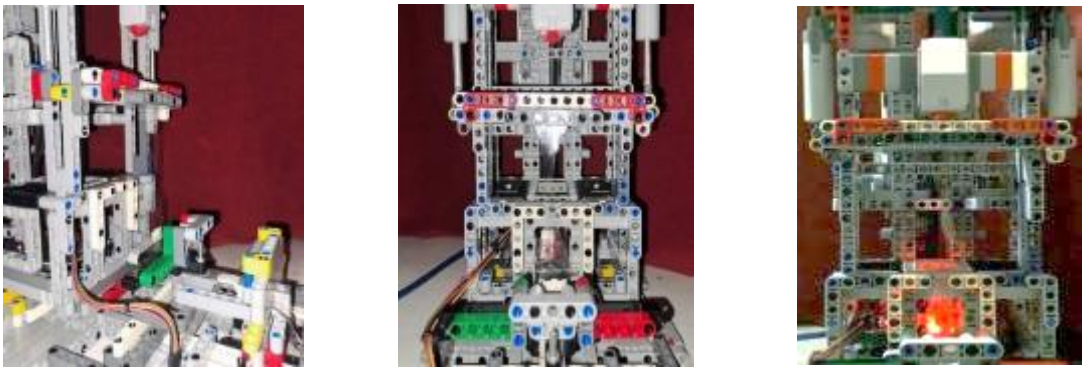


Figure 7. The elongation at break of the films tested on a conventional texture analyser and LEGO®-based Texture Analyser

Next, as the LEGO®-based texture analyser elongation at break test was conducted, the data collected provided a visual and practical understanding of the limitations of the LEGO®-based texture analyser. The elongation at break was determined by converting the extension recorded during the test into a change in gauge length and applying Equation 5. This expresses the percentage increase in length of the film before it broke, relative to its original length. We tested and recorded the elongation at break values for nylon films and films based on 15%, 25%, and 35% glycerol gelatine. The results were 60.61 ± 19.41%, 24.24 ± 7.42%, 52.12 ± 5.21%, and 82.42 ± 7.76%, respectively.



(a) (b) (c)

Figure 8. (a) The position of the films in the LEGO®-based texture analyser, **(b)** initial actuator length and **(c)** final actuator length when the films break.

Based on the values obtained from the conventional and LEGO®-based texture analyser, the percentage deviation of the test was calculated, which was 6.20%. Even though it was innovative and cost-effective, minor inconsistencies in gripping force, stretching speed, or actuator calibration were the reason for the deviation that occurred. Additionally, external factors such as manual film placement or slight slippage during testing may contribute to the deviation.

3.4. Limitation of LEGO®-Based Texture Analyser

Several limitations have inhibited the full potential of a LEGO®-based texture analyser as an affordable alternative to a conventional texture analyser. It can be improved through further research and design optimisation. The limitations identified in this study offered valuable insight for future refinement of the system. The maximum elongation of the LEGO®-based texture analyser is limited to 50 mm, which restricts its ability to test biofilms and synthetic polymers with high flexibility (Talib *et al.*, 2019). During the test, it almost reached the limit of elongation, with a gap of less than 5 mm based on Figures 8 (b) and (c).

To measure the tensile strength of films with increased rigidity, the maximum force output was limited to 5 kg, or 49.05 N. The choice of load cells used in the model was the cause of this. Using a load cell with a greater value, like 10 kg, can increase the capped maximum force output value. Nevertheless, calibration will always be necessary when using a new load cell. When the tensile strength applied to the film stays below a certain threshold, which was around 12 N, the motor can revolve efficiently. It also had a restricted torque capability. This was first tested in order to prevent needless mistakes throughout the test. If it exceeded the limit, the motor rotated unevenly, resulting in erratic pulling speeds that impacted the precision of measurements of tensile strength and elongation.

The data acquired for the LEGO®-based texture analyser had a greater standard deviation than the conventional texture analyser. The LEGO®-based texture analyser exhibited reduced measurement consistency, as indicated by the high standard deviation value. This inconsistency was caused by the limitation of the analyser's gripper mechanism. Notwithstanding these differences, the LEGO®-based approach showed promise for initial or instructional usage, particularly in settings with restricted access to expensive analytical tools.

3.5. Compatibility of Gelatine-based Biofilm to The Model

The compatibility of the fish scale gelatine-based biofilm with the established LEGO-based texture analyser was assessed by comparison to the conventional texture analyser. Preliminary tests indicated that films containing glycerol demonstrated significant flexibility. During this study, only the selected synthetic polymer, such as nylon and biofilms with certain glycerol percentages were used in the LEGO®-based texture analyser mechanical properties test. This selection was made due to the limitations of the current LEGO®-based texture analyser, which had been discussed previously. For example, the maximum elongation of the linear actuator during the test, the maximum force that can be withstood by the linear actuator, and the motor were 50 mm and 12 N.

The nylon, 15%, 25% and 35% glycerol films were the films that were selected in the test on the LEGO-based texture analyser. The data obtained during the test on the LEGO®-based texture analyser were compared with the data obtained during the test on a conventional texture analyser through error calculation using the formula stated in Equation 7. The films made with less glycerol were fragile and likely to fracture even before testing began during the cut, according to ASTM D6882-12 (2012). Most of the synthetic polymers were less compatible with the LEGO-based texture analyser due to high elongation, exceeding the limitation of the model, which was only 151.52% elongation at most. All the synthetic polymers, such as polypropylene (PP), low-density polyethene (LDPE), polyethene (PE) and nylon, were tested initially using the LEGO-based texture analyser, but as the elongation of the material exceeded this limit, only the nylon film was able to proceed with further mechanical properties analysis. This highlighted the best criteria in selecting material that will be tested with the LEGO-based texture analyser.

Several criteria directly influenced the accuracy, precision and repeatability of the LEGO model's performance. Torque stability and gripper alignment were crucial as they control the uniformity of the force and data acquisition during the biofilm test. The

conventional texture analyser or some alternative demonstrated better performance in these criteria due to its superior control mechanisms and better-quality sensors. However, the LEGO®-based texture analyser offered great advantages in terms of cost-effectiveness, flexibility and accessibility, making it a promising tool for educational and preliminary research applications.

4. Conclusions

The LEGO®-based texture analyser demonstrated a budget-friendly option to conventional texture analysers, yielding almost a similar result. This was proven as the percentage of deviation between the conventional texture analyser and the LEGO-based texture analyser for the tensile strength test and elongation at break test was 5.19% and 6.20%. As these values fall below 10%, the instrument can be considered reliable and repeatable for basic tensile testing, in accordance with the GAGE R&R criterion even though some improvement can be made to overcome these limitations. Nonetheless, the device serves as a valuable resource in a setting with limited resources. This prototype model also has great potential to be used in universities and schools as a hands-on teaching instrument to demonstrate the concept of the material mechanical properties and engineering design. In addition, it also offers an affordable way to attract students to STEM learning about biopolymers or mechanical testing. Additional advancements in design and calibration may increase its dependability and expand its use in assessing bioplastic materials. The findings also indicated that a rise in glycerol levels decreased tensile strength but enhanced its elongation at break. The data collected also support the potential of fish scale-derived biopolymers as environmentally friendly alternatives to synthetic plastics, even in a small-scale environment, with the application of a LEGO®-based texture analyser.

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