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Analysis of The Effects of Variable Food Packaging Seals on Tensile Test Results for PET-LDPE-Aluminum Foil Composite Materials

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***Abstract**. This article features experimental findings on the tensile testing procedure conducted on package seals made from Polyethylene Terephthalate (PET)-Low-Density Polyethylene (LDPE)-Aluminum Foil composite materials commonly employed in food packaging applications. This study aims to ascertain the outcomes of the tensile test or tensile strength of the packaging seal utilizing the Auto Tensile Tester XLW according to the ASTM F88 standards. The tensile test involves using two types of variables: independent variables and dependent variables. The study used temperature (°C) and holding time (s) as independent factors, whereas the dependent variable is the tensile test results or tensile strength (N/mm^2). This study utilized identical parameters for each variable. The specimen's measurements were 15mm x 25mm. This experiment included three temperature factors and a constant holding time of 1 second. Every parameter underwent four tests, resulting in twelve test samples. Based on the findings, the optimal temperature range for achieving the most efficient packing sealing was 135ºC. The maximum sealing strength of 17.50 N/mm^2 was attained within this temperature range, and the outcomes were influenced by both the temperature and the duration of the holding period. Each sample has distinct values, encompassing a rather narrow range.*

***Keywords** - seal strength, composite material, food packaging, tensile testing.*

INTRODUCTION

Packaging is important in conveying product information, such as manufacturer, brand, origin, quantity, and ingredients [1]. It also helps control food quality and ensure consumer satisfaction [2]. The significance of packaging is becoming more evident due to modern issues like plastic pollution, packaging waste, declining air quality, soil and water, and climate change [3]. Heat sealing technology is commonly used in the food packaging industry, especially for food items such as snacks, frozen foods, retort bags, and other products. This technology is highly significant as it helps preserve the freshness of food for extended periods. The most commonly used types of films are laminated films that involve the application of heat and pressure to join polymers. During sealing, pressure is first applied to ensure close contact between both film surfaces, followed by heat and pressure from the film's exterior to achieve adhesion. The quality of heat sealing is affected by various crucial factors, including temperature, pressure, duration of the sealing process, as well as the duration of cooling. Many researchers have conducted studies to examine the impact of heat sealing time on the overall effectiveness of the process [4][5][6]. Functional films known as barrier coatings are utilized in the packaging industry to enhance the end-use properties of polymer substrates.

In the case of food packaging, the materials used must ensure that the packaged food is protected from various environmental factors, including moisture, oxygen, and ultraviolet radiation, to preserve its freshness. The most commonly used material for this purpose is aluminum metal film. Roll-to-roll metallizers have emerged as a highly efficient and economical method for producing transparent barrier coatings of materials such as aluminum or silicon. These coatings are specifically engineered to fulfill specific criteria, such as compatibility with microwaves, visibility of the product, or the ability to be reversed. The reason for this is the increasing need for affordable packaging solutions that include transparent barrier film [7]. Heat-sealed plastic bags are extensively employed in many applications, such as food packing and vacuum sealing. Heat sealing technology plays a vital role in the medium packaging industry. Different sealing technologies are employed to achieve the desired heat-sealing properties of a film, which require regulating the temperature, pressure, and duration of sealing. Understanding the characteristics of the heat-sealing film is crucial to comprehend the nature of the heat sea [8]. Heat sealing relies on critical parameters such as temperature, hold time, and applied pressure. The strength of the seal is primarily influenced by the temperature at the interface of the films, which is affected by the temperature of the sealing device and the duration of holding. In contrast, the pressure applied has little impact on the strength of the seal [9]. The study evaluated how heat sealing temperature, time, and pressure modifications affect the strength of five available packaging films. The objective was to determine the optimal conditions that would result in a robust peelable seal appropriate for packaging that is easy to open. The study's findings could have implications for the Hazard Analysis and Critical Control Point (HACCP) system, which deals with the heat-sealing process [10]. Several researchers have conducted studies indicating that the properties of heat-sealing components are linked to the heat-sealing conditions and Heat Seal Strength (HSS) [11].

Djonaedi et al conducted a prior investigation in which they established that during the sealing or bonding process of flexible packaging coated with PET-ALU FOIL-LDPE, it is necessary to attain an adequate temperature to melt both the LDPE and PET layers [12]. According to the results obtained by his research, the ideal sealing strength is 31 N/15mm at 180°C in the TD direction and 34 N/15mm at 160°C in the MD direction. 30N/15mm. Thus, it is unnecessary to raise the temperature to 240°C as it would only lead to higher energy consumption and prolong the sealing process. Yahya et al conducted a research study on drug packaging to examine how temperature and pressure variations impact the adhesive strength of aluminum foil [13]. The researchers used a heat sealing system to perform a packaging seal with various temperature parameters (105ºC, 120ºC, 135ºC, 150ºC, and 165ºC) and sealing roll pressures (1, 1.5, 2, 2.5, and 3 Bar). Afterward, they conducted tension and leakage tests. The results of the study indicated that the greatest adhesion, measuring 31.5 N, was attained by setting the temperature to 165°C and the pressure to 2.5 Bar. On the other hand, the optimal pressure of 2.5 Bar produced an adhesion of 18.1 N. In addition, the study also done by Budianto & Yuda obtained information about the quality of LDPE-Nylon-Al composite materials as flexible packaging using Sealing Strength methods, Fourier Transform Infrared Spectroscopy (FTIR), and SEM-EDX to analyze the effect of temperature on the material, conducting sealing strength test results tension using ASTM F88 standards [14]. The results showed a tensile strength of 106 N. In addition, the analysis of the FTIR spectrum characteristics showed the secondary amide chemical structure N-H, O-Al-OH, and the alkyl C-H function at the frequency points of 3297.66 cm^{-1}, 1199.50 cm^{-1}, and 2933.18 cm^{-1}.

The primary objective of this research is to verify the ability of packaged food to withstand pressure and prevent leaks during storage. The methodology involves a strength seal test on food packaging, aiming to guarantee the freshness and integrity of the product upon reaching consumers. The experimental approach incorporates a quantitative analysis with two variables and 12 samples, as detailed in the information. The independent variables in this study consist of holding time 1 (measured in seconds) and temperature variations, specifically 125, 135, and 140 degrees Celsius. The dependent variable under scrutiny is the tensile strength. This experimental design allows for a systematic exploration of the impact of holding time and temperature variations on tensile strength, providing valuable insights into the packaging's performance and its implications for maintaining the quality of the packaged food.

METHODS

A. Materials

A PET/LDPE/Aluminum Foil composite was required for the study. A thickness of 45 µm (0.045 mm) was observed in the material. This material supported flexible film packaging. A total of 12 samples are utilized in the experimental method to quantify the correlation between two variables, illustrated in Figure 1. The adhesive lamination machine evaluated three laminates for flexible packaging. As illustrated in Figure 1, these laminates consist of three strata: an outer layer composed of 12 µm PET, a middle layer composed of 7 om aluminum, and an inner layer comprising 26 µm LDPE. Printing, barrier, and receiving film layers comprise the majority of flexible packaging laminates. Polymer films coated with metallic substances, transparent barrier films, and non-transparent aluminum foil are all utilized in flexible lamination videos. Employing rolling mills, 7 mm aluminum foil was initially produced as a high-barrier material for flexible food packaging. Substituting metalized film for aluminum foil reduces material expenses and aluminum consumption. A thickness of 7 mm is the norm for flexible laminate aluminum foil. The three commercial barrier films available were aluminum foil (alu) and thin layer met PET. A co-extruded LDPE sealing layer and PET outer layer comprise this barrier film. A metalized film encircles the structure, composed of PET/adhesive/alu/adhesive/LDPE layers. Particularly, the barrier that remains after the test measures the mechanical properties of the primary obstacle, the flexural barrier [15].

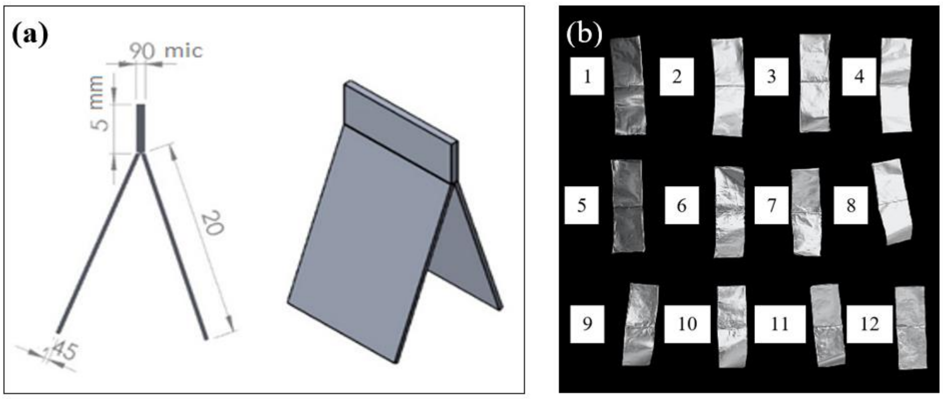

Figure 1. Test Sample design : (a) Sample geometry, (b) 12-sample prepared

B. Experimental setup.

In implementing the works procedure, the initial step entails the meticulous calibration of the tensile testing machine, adhering strictly to the manufacturer's guidelines. Following this, the crucial preparation of sealed samples for testing necessitates strict conformity to the dimensions outlined in the ASTM F88 standard, including the precise cutting of edges to ensure perpendicularity to the sealing direction. The subsequent step involves securing both ends of the specimen to their respective fixtures on the tensile testing machine, emphasizing the need to center the sealing region between the fixtures and ensure the seal line is perpendicular to the tension direction. Adequate slack is recommended to prevent seal compression before test initiation. Additionally, fine-tuning the loading velocity within the optimal range of 250-300 mm/min is crucial for achieving precise and reliable testing conditions [16]. The composite material's structure is visually represented in Figure 2.

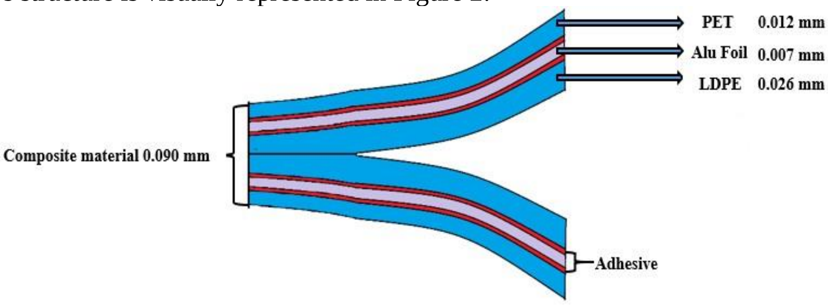

Figure 2. Composite material structure

The mechanical characteristics of the heat-sealed portion were assessed through a peeling test, involving the evaluation of a sample measuring 15 mm in width and 25 mm in length. Figure 1 (a) provides a diagrammatic representation of the specimen post heat-sealing process, illustrating the configuration under examination. This peeling test serves as a valuable method for scrutinizing the mechanical attributes of the heat-sealed component, offering insights into the effectiveness and integrity of the sealing process.

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C. Tensile Seal Strength (TSS)

Tensile testing is the application of force or tensile stress to a material to detect and determine the strength of the material. The stress used in the tensile test is the actual stress or extension on the object's axis [17]. he tension test method is a means of assessing the strength of a material. It entails exerting a force in the same direction as the tested material but in the opposite direction [18]. Tensile stress and strain can be analyzed through mechanical properties such as tensile strength, yield strength, Young's modulus, Poisson's ratio, elongation, and reduction in area. These properties can provide valuable information regarding the deformation behavior of a material. In addition, material properties can be used to determine true stress and strain properties, as well as strain hardening and tensile toughness, using specific equations derived from stress-strain curve data [19]. The basic principles in the mechanics of materials are stress and strain. To explain this principle, we can observe a prismatic rod subjected to an axial force [20]. Therefore, equation (1) can be obtained as the following method to express the magnitude of stress [21] .

$$б = \frac{P}{A} \tag{1}$$

In the given symbols, representing parameters relevant to the study of material mechanics, P stands for the force or load applied to the material, measured in Newtons (N). A denotes the cross-sectional area of the material, expressed in square millimeters (mm^2). Finally, (σ) represents stress, measured in Newtons per square millimeter (N/mm^2) [22].

The validity of Equation (2) stems from the uniform distribution of stress across the entire cross-sectional area of the rod, with the axial force P being applied precisely at the centroid of the component. If the load P is not applied precisely at the center of gravity, the rod will experience deviation, which requires more complex calculations. Unless explicitly stated otherwise, it is commonly assumed that the axial force is exerted at the centroid of the section [20]. When a force P is applied to the right end of an object, it experiences a characteristic process of elongation. The application of this force will result in an equivalent reaction at the left end, subsequently generating normal stress on that side. The calculation of normal stress can be determined using specific equations. When an object is exposed to a tensile force P, it undergoes an increase in both its length and cross-sectional area [23]. The theoretical elongation or stretch (ε) can be calculated by dividing the increase in length by the original length of the object, as shown in equation [24].

$$\varepsilon = \frac{\Delta L}{L_0} = \frac{L - L_0}{L_0} \tag{2}$$

In the context of material science and mechanics, the symbols represent key parameters in the study of tensile properties. ε denotes tensile strain, a measure of the deformation or elongation of a material subjected to pulling forces. ΔL represents the change in length, measured in meters (m), reflecting the difference in length after the application of force L0 signifies the initial length in meters, indicating the original length of the material before any deformation occurs. This notation is fundamental in expressing the relationship between tensile strain and the alteration in length, offering valuable insights into the mechanical behavior of materials under tensile stress.

The strain (ε) is defined as the change in length (ΔL) divided by the initial length (L0). It is typically expressed in units of mm/mm or m/m and can be either measurable or immeasurable [25]. In some cases, strain is presented as a percentage. Within the elastic region, where the material's length can change, it demonstrates properties that are either proportional to or directly proportional to the stress applied to it. The elastic modulus, denoted as E and defined by equation (3), establishes a linear correlation referred to as the longitudinal elastic modulus or Young's modulus in the presence of a change in size [26]. The relationship between these symbols is established by Hooke's Law, which states that the modulus of elasticity (E) in N/m2 is equivalent to the ratio of tensile stress (σ) in N/m2 to tensile strain (ε). This relationship allows us to understand how well a material can regain its original shape after being deformed.

$$E = \frac{\sigma}{\varepsilon} = L_0 \frac{\sigma}{L - L_0} \quad (3)$$

The first step in the execution of the works procedure requires precise calibration of the tensile testing machine, following the manufacturer's guidelines with great attention to detail. Consequently, it is crucial to strictly follow the dimensions specified in the ASTM F88 standard when preparing sealed samples that are necessary for testing.This procedure involves the meticulous trimming of edges to guarantee that they are at a right angle to the sealing direction.The next step is to fasten both ends of the specimen to their respective fixtures on the tensile testing machine. It is important to center the sealing region approximately between the fixtures and make sure that the seal line is perpendicular to the direction of tension. In order to avoid seal compression prior to the start of the test, it is recommended to have a sufficient amount of slack. Furthermore, adjust the loading speed to fall within the optimal range of 250-300 mm/min in order to attain accurate and dependable testing conditions. The two legs are firmly attached to the holder, as depicted in Figure 3.

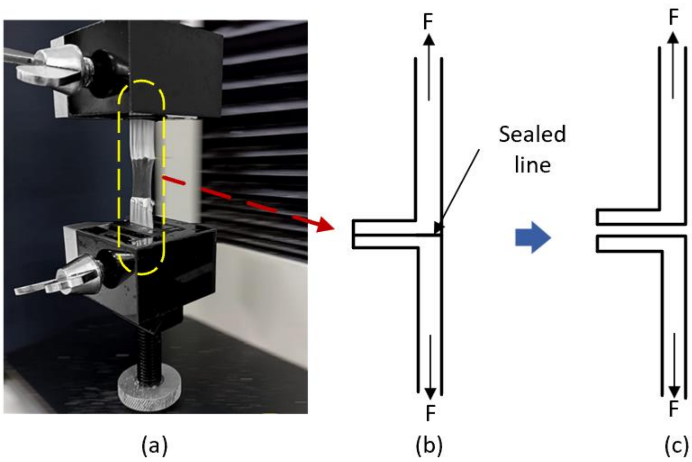

Figure 3. Stress Testing Process: (a) Tensile test devices, (b) Before test, (c) After test.

To assess the mechanical properties of the heat-sealed region, peeling experiments were conducted on specimens measuring 25mm in length and 15mm in width. Throughout the experiment, the samples were subjected to a consistent loading velocity of 100 mm/min, and the coalescence (mm) and force F (N) were measured and documented [27]. Each material and sealing condition underwent testing using a total of 12 specimens. The F/W data was recorded as a locking function, with only one representative datum reported for each test. The assessment of the strength required for heat sealing was conducted through the calculation of the apparent sealing strength. The value was derived by dividing the maximum force (Fmax) by the nominal width (W) which can be calculated by using equations (4). A standard tensile seal strength (TSS) was defined and utilized to account for the variation in sample thickness caused by the number of layers.

$$TSS = \frac{F_{max.}}{W \times t} \quad (4)$$

The nominal width (W) and film thickness (*t*) is also described in millimeters (mm) and N/mm^2, respectively, and Fmax is the maximum force required to complete the heat seal in newtons (N) and SS is equivalent to these units [5]. In order to compare the outcomes of peeling and tensile tests, the nominal stress is computed as F/(L0e) in both instances, passing through the engineering strain: (L/L0) for peeling and tensile tests and (L/2L0) for both. Samples measuring 25 mm in length and 15 mm in width were subjected to testing with identical apparatus for all materials in order to acquire precise yield stresses for the film under investigation. In order to stabilize the initial thickness of the film samples, the experiments were carried out at a consistent crosshead speed.

As depicted in Figure 4, the research utilized a heat-sealing apparatus that integrated heating and cooling phases. Figure 5 illustrates the two varieties of heat-sealing rods, each measuring 10 mm in width, employed during the heat-sealing phase: knurled and flat-shaped rods. On the contrary, a solitary set of 15 mm wide flat bars was utilized during the cooling phase [27]. Spacers were used in industrial settings to determine the minimum distance between the heat-insulating and cooling bars. The design of this apparatus facilitated an exhaustive investigation into heat-sealing processes by integrating different types of rods and cooling parameters to evaluate their influence on the ultimate heat-sealed product.

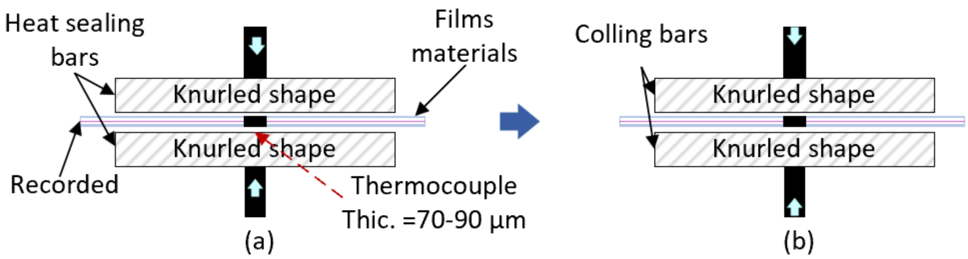

Figure 4. Schematic of heat sealing equipment: (a) Heat sealing stage (b) Colling stage

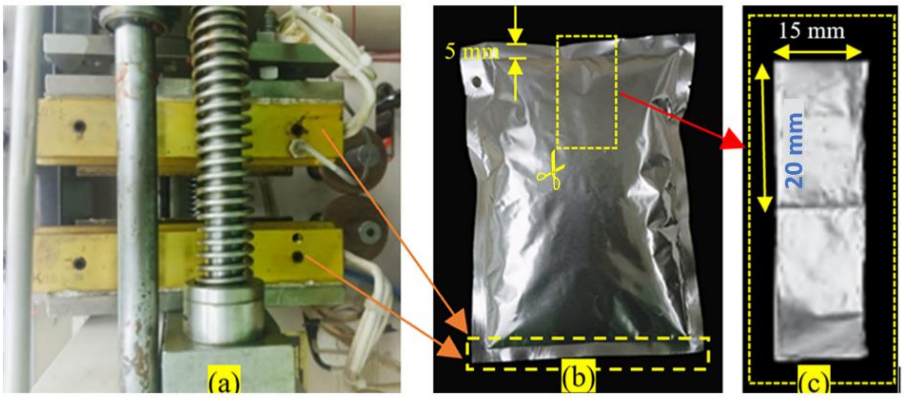

Figure 5. Schematic of top and bottom heat sealing rods: (a) Heating knurled shape devices (b) Sample of packaging (c) Sample of TSS.

This study demonstrated that if the heat-sealing temperature is significantly lower than the melting temperature of the sealant, it leads to a failure mode referred to as flaking. This mode entails the separation and removal of the chain end from the opposing surface, resulting in the delamination of the heat seal bond, as illustrated in Figure 3. Flaking is the result of a seal that is not as strong as the laminated structure strength (SL) [28]. This causes the heat-sealing strength (HSS) of all failed samples in this mode to be lower than in other failure modes [28]. Hence, failure in this mode transpires within these particular circumstances. Heat sealing strength can be calculated by using equations (5).

$$HSS - SL < 0 \tag{5}$$

Where HSS described for heat-sealing strength in N/mm ($HSS = \frac{F_{max.}}{W}$) and *SL* donated for laminated structure strength in N/mm ($SL = \frac{F_{max.}}{L}$). The value of *W* and *L* are 15 mm and 5 mm, respectively.

D. Statistical validations

Important aspects that require careful attention for heat sealing include the choice of seal coating material, the amount of seal pressure applied, the duration of seal residence, and the seal temperature. Swiftly achieving the desired Heat Seal Strength (HSS) is also crucial from an industrial perspective [29]. The expansion of film polymerization's usage in the production of flexible packaging depends significantly on its thermal conductivity, making it one of the most critical criteria to consider [30][31]. In thermal bonding, two films are put between two heated metal bars, and pressure is kept on them until the polymer melts at high temperatures and lets the films interact. The strength of the seal shows how well the packaging is made, and the film usually stays at the temperature it was at first. It is important to test how well the package works to fully understand how each thermally bonded material can fail and determine if two layers are right. Ensuring the molecules in the layers interact properly is important for getting a good seal on the package. This section discusses the results of Aiyengar and Divecha's study on heat seal strength from 2012. Using a central composite design methodology that was repeated [32], they carefully looked into important process variables while creating a model for heat seal strength. By adding temperature (X1), holding time (X2), and pressure (X3) to their model, the researchers were able to find possible interactions and higher-order effects that would help them find the best conditions for operation. The study used the central composite design to test 36 different combinations of residence time, sealing temperature, and pressure. In order to ascertain the outcomes, samples were meticulously prepared and subjected to testing using all 36 conceivable treatment permutations. The average heat seal strength (HSS) was determined by conducting tests on ten samples of each combination. Each treatment mixture's standard deviations (σ) ranged from 10 to 15 grams per inch (g/in). The equation (6) is a statistical formula for storing the independent process variables [21].

$$x_i = \frac{X_i - X_0}{\delta X_i} \tag{6}$$

In the experimental design context, the notation is as follows: Xi represents the actual value of the experimental variable, $X0$ stands for the midpoint or center point of Xi, ΔXi signifies the step change or increment in Xi, and xi denotes the code value assigned to Xi, with i taking on values of 1, 2, or 3.

RESULTS AND DISCUSSIONS

Tensile load test analysis

The outcomes of the tensile load test conducted to assess the heat sealing properties at temperatures of 125°C, 135°C, and 140°C, with a holding time of 1 second following the ASTM F88 test standard, demonstrate a uniform and stable sealing strength for the 12-layered samples post-test. The experimental results were obtained using a tensile testing machine, and the specific data is provided in Table 1 below. This table provides a thorough reference, presenting information on the sealing strength performance at different temperatures. It contributes valuable insights into the behavior of the heat-sealed samples.

Table 1. ASTM F-882 tensile strength test results

Test material	Variation		F Max (N)
	Temperature (°C)	Hold Time (sec)	
Al, PET, LDPE	125	1	9,57 8,98 9,01 10,57
Al, PET, LDPE	135	1	11,53 11,58 11,81 11,18
Al, PET, LDPE	140	1	9,98 13,84 13,36 8,08

Seal Strength Analysis

Seal strength calculated by using equation (4). Figure 6 depicts the correlation between time and temperature and seal strength of the samples. It demonstrates that the temperature required to seal the two films is achieved within seconds. These findings indicate that the inner surface coating achieves the sealing temperature within one second. Experiments were performed to test the heat-sealing properties of PET, LDPE, and Aluminum Foil samples. The interface temperatures ranged from 125°C to 140°C. Every data point in Figure 7 is marked with the identified failure mode and seal strength. As the interface temperature rises to 135°C, there is a notable augmentation in the skin seal strength of the material sample. On the other hand, a flaking failure mode arises when the temperature for heat sealing is significantly lower than the melting point of the sealant, leading to a lower heat sealing strength than other failure modes [21].

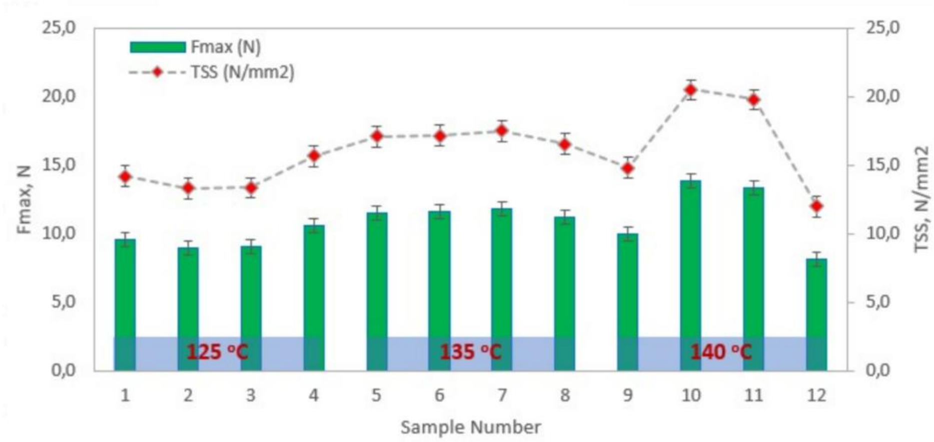

Figure 6. Seal-strength of the experiment

The load test and displacement correlation are depicted in Figure 7. At 125°C, with a holding time of 1 second, all sealing layers are in the solid state, obtaining a range of <11 N. Upon increasing the temperature to 135°C, simulation results suggested that the most favorable sealing layer exhibited a force exceeding 11 N. It was attributed to the smaller temperature gradient, increasing heat loss in the sample. The result explains why the holding time was low when the film was sealed at 125°C for 1 second. However, at the sealing temperatures of 135°C and 140°C, result stability was observed under the same conditions. Additionally, the removal time can impact the material's tensile strength. However, in this case, the removal time used is consistent, i.e., 1 second, indicating that the removal time factor does not affect the tensile test result [32].

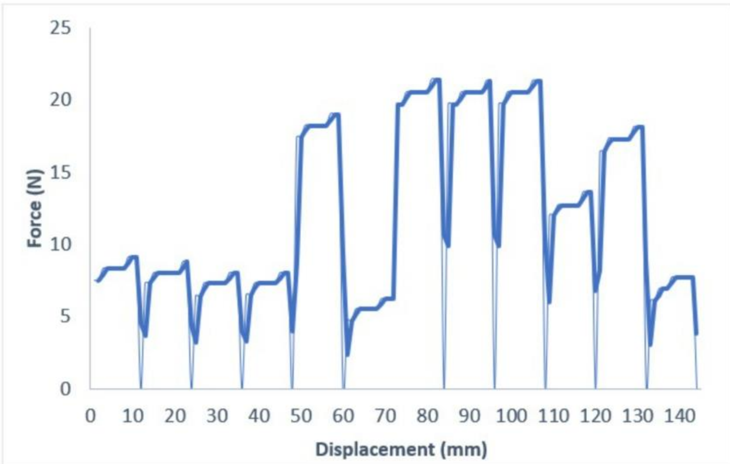

Figure 7. Force and displacement graph

Statistical analysis

Table 2 displays the computed cooling force values obtained by applying equation (4), deviation values, and the experimental results of the maximum force. In addition, the table presents the ratio of experimental data calculated using various deviations in tensile seal strength (*TSS*). The findings demonstrate that different sealing strengths are observed in composite materials for each test examined. The mean discrepancy between the TSS value and the maximum force is 15.99. The most favorable deviation outcomes were recorded at a temperature of 135°C, where the maximum force exceeded 11.81 N, and the heat seal strength (*SS*) surpassed 17.5 N/mm². The comparatively low error percentage less than 10%. In contrast, at temperatures of 125°C and 140°C, the deviation value is significantly higher, resulting in a large and irregular relative error. The relative error percentage is specified in Table 2, with an average of 13.21%.

Table 2. Calculation of experimental data ratios using deviation values

No.	**Temp.** (°C)	**F Max. (N)**	**SS (*Seal Strength*) (N/mm^2)**	**Average**	**Std. Deviate**	**Error (%)**
1		9.57	14.18	14.10	1.10	0.1%
2	125	8.98	13.30	14.10	1.10	5.7%
3		9.01	13.34	14.10	1.10	5.4%
4		10.57	15.66	14.10	1.10	11.0%
5		11.53	17.08	17.07	0.38	0.1%
6	135	11.58	17.16	17.07	0.38	0.5%
7		11.81	17.50	17.07	0.38	2.5%
8		11.18	16.56	17.07	0.38	3.0%
9		9.98	14.79	16.76	4.08	11.8%
10	140	13.84	20.50	16.76	4.08	22.3%
11		13.36	19.79	16.76	4.08	18.1%
12		8.08	11.97	16.76	4.08	28.6%

CONCLUSIONS

The tensile load test is an important tool for understanding how the shape of the heat insulation rod affects the heat sealing process of composite films, particularly those made of PET-LDPE-aluminum Foil. The peel strength of the heat-sealed film is influenced by its internal structure, which has the potential to be improved. Ensuring precise control over the heat sealing process and carefully choosing the shape of the sealing rod are crucial in enhancing the characteristics of the packaged product. This study conducts a thorough examination of the influence of sealing temperature and holding time, with specific emphasis on a one-second duration of holding. The results indicate that the highest tensile strength is attained at elevated sealing temperatures, specifically at 135°C, yielding a tensile strength of 17.50 N/mm2 and an error percentage below 10%. These findings emphasize the significance of accurate heat sealing parameters for enhanced product qualities.

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REFERENCES

[1] H. N. J. Schifferstein, A. de Boer, and M. Lemke, “Conveying information through food packaging: A literature review comparing legislation with consumer perception,” *J. Funct. Foods*, vol. 86, p. 104734, 2021, doi: https://doi.org/10.1016/j.jff.2021.104734.

[2] A. Conte, L. Angiolillo, M. Mastromatteo, and M. A. Del Nobile, “Technological Options of Packaging to Control Food Quality,” in *Food Industry*, I. Muzzalupo, Ed. Rijeka: IntechOpen, 2013, p. Ch. 16. doi: 10.5772/53151.

[3] Z. Boz, V. Korhonen, and C. K. Sand, “Consumer considerations for the implementation of sustainable packaging: A review,” *Sustain.*, vol. 12, no. 6, Mar. 2020, doi: 10.3390/su12062192.

[4] S. D. Mihindukulasuriya and L.-T. Lim, “Heat sealing of LLDPE films: Heat transfer modeling with liquid presence at film–film interface,” *J. Food Eng.*, vol. 116, no. 2, pp. 532–540, 2013.

[5] E. Planes, S. Marouani, and L. Flandin, “Optimizing the heat sealing parameters of multilayers polymeric films,” *J. Mater. Sci.*, vol. 46, pp. 5948–5958, 2011.

[6] K. Yamada, K. Miyata, R. Konishi, T. Tsujii, and Y. Hashimoto, “Heat seal processing by using various seal

bar shape," in *AIP Conference Proceedings*, 2015, vol. 1664, no. 1, p. 080002.
[7] C. F. Struller, P. J. Kelly, and N. J. Copeland, "Aluminum oxide barrier coatings on polymer films for food packaging applications," *Surf. Coatings Technol.*, vol. 241, pp. 130–137, 2014, doi: https://doi.org/10.1016/j.surfcoat.2013.08.011.
[8] S. Farris and L. Piergiovanni, "Emerging coating technologies for food and beverage packaging materials," in *Emerging food packaging technologies*, Elsevier, 2012, pp. 274–302.
[9] S. Mihindukulasuriya and L. Lim, "Effects of liquid contaminants on heat seal strength of low-density polyethylene film," *Packag. Technol. Sci.*, vol. 25, no. 5, pp. 271–284, 2012.
[10] D. Aithani, H. Lockhart, R. Auras, and K. Tanprasert, "Predicting the strongest peelable seal for 'easy-open'packaging applications," *J. Plast. Film Sheeting*, vol. 22, no. 4, pp. 247–263, 2006.
[11] M. Nase, S. Bach, A. Zankel, J. Majschak, and W. Grellmann, "Ultrasonic sealing versus heat conductive sealing of polyethylene/polybutene-1 peel films," *J. Appl. Polym. Sci.*, vol. 130, no. 1, pp. 383–393, 2013.
[12] E. Djonaedi, D. Ayu, and D. Handayani, "VARIASI TEMPERATUR TERHADAP PERUBAHAN NILAI KEKUATAN SEAL PADA MATERIAL KEMASAN LENTUR MULTI LAYER PET-ALU FOIL-LDPE," *J. Poli-Teknologi*, vol. 18, no. 3, pp. 255–260, 2019.
[13] F. A. Yahya *et al.*, "Pengaruh temperatur dan tekanan terhadap daya rekat aluminium foil pada bahan pengemas obat," no. Ciastech, pp. 281–286, 2019.
[14] B. Budianto, Y. Dwi Adhi H, and S. Max Yuda, "Analisa Pengaruh Temperatur Sealing terhadap Kuat Tarik dan Gugus Fungsi pada Material Komposit LDPE-NILON-AL sebagai Fleksibel Packaging," *J. Rekayasa Energi dan Mek.*, vol. 2, no. 1, p. 54, 2022, doi: 10.26760/jrem.v2i1.54.
[15] C. Ge, S. S. Verma, J. Burruto, N. Ribalco, J. Ong, and K. Sudhahar, "Effects of flexing, optical density, and lamination on barrier and mechanical properties of metallized films and aluminum foil centered laminates prepared with polyethylene terephthalate and linear low density polyethylene," *J. Plast. Film Sheeting*, vol. 37, no. 2, pp. 205–225, Oct. 2020, doi: 10.1177/8756087920963532.
[16] "Standard Test Method for Seal Strength of Flexible Barrier Materials 1", doi: 10.1520/F0088_F0088M-15.
[17] A. Sastranegara, "Mengenal Uji Tarik dan Sifat-sifat Mekanik Logam," *Situs Inf. Mek. Mater. dan manufaktur*, 2009.
[18] R. D. Salindeho, J. Soukotta, and R. Poeng, "Pemodelan pengujian tarik untuk menganalisis sifat mekanik material," *J. POROS Tek. MESIN UNSRAT*, vol. 2, no. 2, 2013.
[19] W. Lim and H.-K. Kim, "Design and development of a miniaturised tensile testing machine," *Glob. J. Eng. Educ.*, vol. 15, no. 1, pp. 48–53, 2013.
[20] J. M. Gere, S. P. Timoshenko, W. Hardani, and B. Suryoatmono, *Mekanika bahan*. Erlangga, 2000.
[21] S. Sukarman *et al.*, "Optimization of tensile-shear strength in the dissimilar joint of zn-coated steel and low carbon steel," *Automot. Exp.*, vol. 3, no. 3, pp. 115–125, 2020.
[22] N. Rahdiana and A. suhara, "Analisis Spring-back dan Spring-go pada Variasi Sudut V-Dies Bending Menggunakan Material Baja Lembaran SGCC Galvanized Analysis of Spring-back and Spring-go on Variation of V-Dies Bending Angle Using Galvanized SGCC Steel Sheet," *J. Tek. Mesin Mech. Xplore Mech. Eng.*, vol. 3, no. 1, pp. 17–25, 2022, [Online]. Available: https://journal.ubpkarawang.ac.id/index.php/JTMMX
[23] S. Sukarman and A. Abdulah, "Optimasi parameter resistance spot welding pada pengabungan baja electro-galvanized menggunakan metode Taguchi," *Din. Tek. Mesin*, vol. 11, no. 1, p. 39, 2021, doi: 10.29303/dtm.v11i1.372.
[24] S. T. Marthen Paloboran, I. H. M. Yahya, and A. E. IPU, *MEKANIKA BAHAN TEKNIK MESIN*. SCOPINDO MEDIA PUSTAKA, 2021.
[25] B. Kristiawan, N. Fazrin, and A. Suhara, "Mechanical Engineering for Society and Industry Tensile shear load in resistance spot welding of dissimilar metals : An optimization study using response surface methodology," vol. 3, no. 2, pp. 66–77, 2023.
[26] T. Surdia and S. Saito, "Pengetahuan Bahan Teknik, Cetakan Ke-4," *Jakarta, PT. Pradnya Paramita*, 1999.
[27] T. Iwasaki, W. Takarada, and T. Kikutani, "Effect of processing conditions on heat seal strength for peelable heat sealing of multilayered polyethylene films with different sealant layers," *J. Macromol. Sci. Part B*, vol. 56, no. 9, pp. 709–723, 2017.
[28] C. S. Yuan, A. Hassan, M. I. Ghazali, and A. F. Ismail, "Heat-seal strength analysis of laminated films with LLDPE and ldpe sealant materials in bar sealing application," in *FEIIC Seminar on Engineering and Technology*, 2006, pp. 4–5.
[29] Z. Najarzadeh and A. Ajji, "A novel approach toward the effect of seal process parameters on final seal strength and microstructure of LLDPE," *J. Adhes. Sci. Technol.*, vol. 28, no. 16, pp. 1592–1609, 2014.
[30] P. Tongnuanchan, S. Benjakul, T. Prodpran, S. Pisuchpen, and K. Osako, "Mechanical, thermal and heat sealing properties of fish skin gelatin film containing palm oil and basil essential oil with different

surfactants," *Food Hydrocoll.*, vol. 56, pp. 93–107, 2016.
[31] C. Liu *et al.*, "Heat sealable soluble soybean polysaccharide/gelatin blend edible films for food packaging applications," *Food Packag. Shelf Life*, vol. 24, p. 100485, 2020.
[32] O. V López, C. J. Lecot, N. E. Zaritzky, and M. A. García, "Biodegradable packages development from starch based heat sealable films," *J. Food Eng.*, vol. 105, no. 2, pp. 254–263, 2011.