

Analysis of Testing on Polyester Capacitors Using an Auto Hot Press Machine

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Abstract: The quality of polyester capacitor elements is strongly influenced by the operating conditions of the hot press process. This study aimed to evaluate the effects of pressure, temperature, and pressing time on the quality characteristics of 27.5-pitch polyester capacitor elements processed using an Auto Hot Press machine. A quantitative exploratory experimental design was applied by evaluating 27 combinations of three pressure levels (5.5, 6.0, and 6.5 bar), three temperature levels (115, 120, and 125 °C), and three pressing-time levels (3, 4, and 5 min). The evaluated responses included visual quality, capacitance tolerance, stiffness, thickness, and processing time. The results showed that low pressure and temperature conditions tended to produce insufficient sealing and low stiffness, whereas higher temperature and pressure conditions were associated with excessive deformation, burning, and capacitance deviations beyond the specified tolerance. The parameter combinations of 6.0 bar and 120 °C with pressing times of 3 and 4 min produced acceptable results, with capacitance deviations of +0.5% and -0.2% and stiffness values of 10.5 and 12.0 kg, respectively. These results indicate that controlling pressure, temperature, and pressing time simultaneously is important for maintaining the electrical, mechanical, and visual quality of capacitor elements. Within the tested experimental range, 6.0 bar, 120 °C, and 3–4 min provided suitable process conditions for achieving the specified product quality criteria while reducing processing time compared with the previous manual process.

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INTRODUCTION

In the current era of industrial development, the increasing use of technology has encouraged manufacturers to improve both production efficiency and product quality. Electrical components are an important part of various industrial applications, and capacitors are among the components that require consistent quality because their electrical and physical characteristics affect product performance. A capacitor is an electrical component that temporarily stores electrical energy (Marriauwaty & Fajrah, 2020). Quality control is therefore an important aspect of capacitor manufacturing because variations in production conditions may affect the consistency and conformity of the resulting products. Previous research on capacitor production has also emphasized the importance of quality control in maintaining product quality during manufacturing processes (Marriauwaty & Fajrah, 2020). In addition, an understanding of electronic components and their material characteristics is important when evaluating manufacturing processes because material properties can influence the performance of the resulting components (Basri & Irfan, 2018). Therefore, controlling the manufacturing process is important to ensure that capacitor elements meet the specified quality requirements.

PT. MEK is a manufacturing company that produces capacitors, inductors, sensors, and piezoelectric devices for various industrial applications. One of the production processes used in capacitor manufacturing is the hot press process. The auto hot press machine applies pressure and heat to the capacitor element to obtain the required physical form and characteristics. The process

therefore requires appropriate control of operating parameters, including track setting, bowl feeder speed, ring speed, temperature, and press bar setting. Mubarot (2017) explains that a hot press machine applies pressure to material while utilizing heat during the processing stage. The application of hot pressing is also closely related to the physical and mechanical characteristics of polymer-based materials. Previous research has demonstrated that hot press parameters can influence the physical and mechanical properties of polymer and composite materials, indicating the importance of controlling temperature, pressure, and processing conditions during hot pressing (Abd Ghani et al., 2020; Younesi & Bahrololoom, 2010). In the context of polymer dielectric capacitors, material characteristics and manufacturing processes are also important considerations because they influence the resulting performance and production quality of capacitor components (He et al., 2025).

Previous studies have demonstrated the importance of controlling hot press conditions in capacitor manufacturing. Research on metallized film capacitors has examined the effects of hot-press setting time and winding tension on capacitor element performance. The findings indicate that hot-press conditions can affect the internal condition and performance of capacitor elements by influencing residual stress, film shrinkage, and the removal of air and moisture from the element (Cui et al., 2023). Research on polyester film capacitors has also shown that hot pressing is an important stage in the formation of capacitor elements and that temperature and pressure conditions influence the resulting element characteristics. Research on the effects of applied temperature and pressure in hot pressing has further demonstrated that variations in processing conditions can affect the mechanical properties of polymer-based materials (Younesi & Bahrololoom, 2010). These studies indicate that hot press parameters are important for controlling capacitor quality. However, previous studies have generally focused on specific process parameters or electrical and structural performance and have not specifically evaluated the combination of production parameters applied to 27.5-pitch capacitor elements using a simultaneous assessment of visual quality, capacitance tolerance, stiffness or hardness, thickness, and processing time.

This condition indicates a research gap in the practical evaluation of hot press parameters for 27.5-pitch capacitor elements. In the production environment, the suitability of a hot press setting cannot be determined from a single quality characteristic because the process may simultaneously affect the physical appearance, electrical capacitance, mechanical stiffness, dimensional characteristics, and processing efficiency of the element. The evaluation of capacitance is particularly important because capacitance is related to dielectric characteristics and the physical configuration of capacitor materials. Previous research has discussed methods for measuring capacitance and evaluating dielectric characteristics in polymer layers, providing a relevant basis for evaluating the electrical characteristics of capacitor elements (Iansyah & Handayani, 2020). Therefore, an integrated evaluation of these characteristics is required to identify a process setting that can satisfy the applicable quality requirements while considering production time.

The present study addresses this gap by analyzing capacitor elements with a 27.5 pitch processed using an auto hot press machine. The analysis considers several quality characteristics simultaneously, including visual quality, capacitance tolerance, stiffness or hardness, thickness, and processing time. Visual inspection is performed to identify defects such as open sealing, damaged elements, dents, burned elements, and unassembled sealing. Quality control in manufacturing can be used to identify product defects and factors contributing to production rejects, making defect identification an important component of production quality evaluation (Mohammad, 2020). Capacitance is evaluated using an AX-321A Digital Checker with an allowable tolerance of -5% to 5%, while hardness and thickness are evaluated using a hardness and thickness gauge. The selection and application of appropriate measurement instruments are important in quantitative research because measurement instruments must be suitable for the characteristics being evaluated (Nasution, 2016). The stiffness range applied in this study is 4 kg to 17 kg.

The novelty of this study lies in the application and evaluation of a specific combination of auto hot press operating parameters to 27.5-pitch capacitor elements using multiple quality indicators simultaneously. Unlike an evaluation based only on electrical performance or a single physical characteristic, this study combines visual inspection, capacitance tolerance, stiffness or hardness, thickness, and processing time to assess the suitability of the hot press process. This approach provides a practical basis for identifying process conditions that meet product quality requirements while also considering production efficiency. Production efficiency can be evaluated by considering the resources and processing time required to produce the desired output. Previous research has examined production efficiency and the effectiveness of production machinery as a basis for evaluating production performance (Kartikasari, 2009; Sahara et al., 2015). Accordingly, processing time is included in the present study as an additional indicator for evaluating the suitability of the hot press operating conditions.

The objective of this study is to determine the quality characteristics of capacitor elements produced using the auto hot press machine and to identify the applicable limits of visual quality, capacitance tolerance, hardness or stiffness, and thickness. In addition, this study evaluates the processing time associated with the applied machine settings. The results are expected to provide a basis for determining appropriate hot press settings for 27.5-pitch capacitor elements and for reducing product rejects and unnecessary machine operating time in the production process.

RESEARCH METHOD

This study used a quantitative approach with an exploratory experimental design supported by field observation and direct process observation. The experiment was conducted to evaluate the effect of three operating parameters of the pneumatic-based Auto Hot Press machine, namely pressure (press bar), temperature, and pressing time (dwelling time), on the quality of 27.5-pitch polyester capacitor elements.

The evaluated quality characteristics consisted of visual quality, capacitance tolerance, hardness or stiffness, thickness, and processing time. The research was conducted through several stages, including field observation, identification of process parameters, experimental design, capacitor element processing, quality inspection and measurement, and comparison of the experimental results with the applicable production criteria.

Research Design

The research design was developed based on observations of the capacitor element production process and the operating conditions of the Auto Hot Press machine. The experimental process began with field observation and identification of the relevant production parameters. The three parameters selected for investigation were pressure, temperature, and pressing time.

The three parameters were each divided into three levels. The combination of the three levels of each parameter produced 27 experimental conditions, calculated as:

$$3 \text{ pressure levels} \times 3 \text{ temperature levels} \times 3 \text{ pressing-time levels} = 27 \text{ experimental conditions.}$$

The experimental workflow is presented in Figure 1.

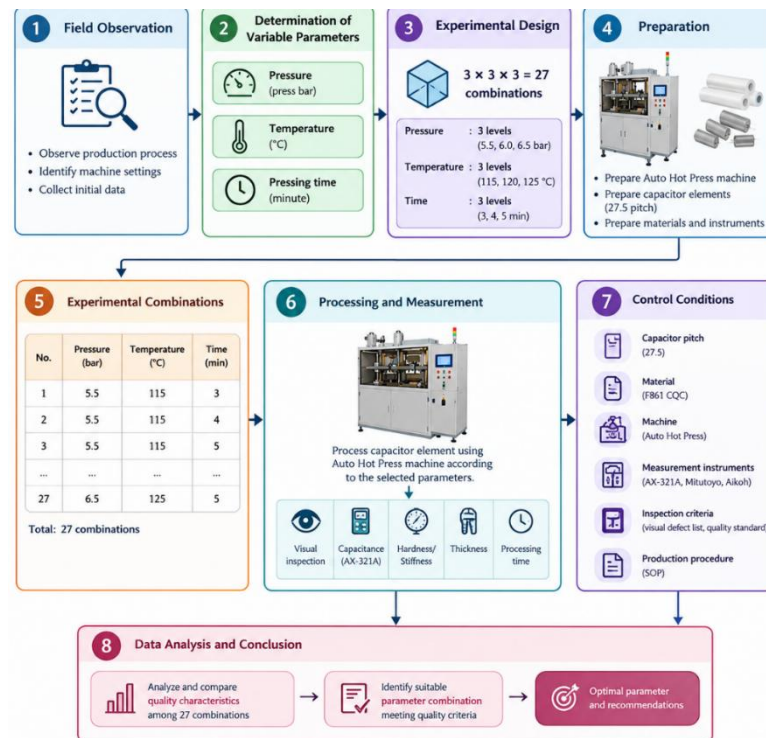


Figure 1. Research design and experimental workflow

The experimental workflow consisted of the following stages:

1. field observation and identification of the production process;
2. determination of the experimental parameters;
3. preparation of the machine, materials, and measurement instruments;
4. arrangement of the 27 experimental parameter combinations;
5. processing of 27.5-pitch capacitor elements using the Auto Hot Press machine;
6. visual inspection and measurement of capacitance, hardness or stiffness, thickness, and processing time;
7. comparison of the results with the applicable quality criteria; and
8. identification of parameter combinations that produced the required product characteristics.

Experimental Variables and Parameter Levels

Field observations indicated that the conventional manual molding process used a pressure of approximately 72,000 N, a temperature of 120 °C, and a processing time of approximately 5–7 minutes. These conditions provided the practical basis for evaluating alternative operating conditions using the Auto Hot Press machine.

Three operating parameters were investigated in the experiment. The first parameter was pressure, expressed as press bar, which controls the pneumatic force applied to the capacitor element. The pressure range investigated was 5.5–6.5 bar. The second parameter was temperature, which was investigated within the range of 115–125 °C. The third parameter was pressing time or dwelling time, which was investigated within the range of 3–5 minutes.

The parameter levels were selected based on the operating range observed in the production process and the work instruction used for the Auto Hot Press machine. The selected levels represent practically applicable operating conditions for processing 27.5-pitch capacitor elements. The experiment therefore focused on variations within the applicable machine and production range rather than conditions outside normal operation.

Table 1. Experimental Parameter Levels

Parameter	Level 1	Level 2	Level 3
Pressure (bar)	5.5	6.0	6.5
Temperature (°C)	115	120	125
Pressing time (min)	3	4	5

The three levels of each parameter were combined systematically, resulting in 27 experimental conditions.

Experimental Combination

The experimental matrix was constructed by combining every pressure level with every temperature level and every pressing-time level. This resulted in a full combination of the three investigated parameters.

Table 2. Experimental Combination of Auto Hot Press Parameters

No.	Pressure (bar)	Temperature (°C)	Pressing Time (min)
1	5.5	115	3
2	5.5	115	4
3	5.5	115	5
4	5.5	120	3
5	5.5	120	4
6	5.5	120	5
7	5.5	125	3
8	5.5	125	4
9	5.5	125	5
10	6.0	115	3
11	6.0	115	4
12	6.0	115	5
13	6.0	120	3
14	6.0	120	4
15	6.0	120	5
16	6.0	125	3
17	6.0	125	4
18	6.0	125	5
19	6.5	115	3
20	6.5	115	4
21	6.5	120	3
22	6.5	120	5
23	6.5	125	3
24	6.5	125	4
25	6.5	125	5
26	6.5	120	4
27	6.5	120	5

Each row represents one distinct experimental condition. The experimental condition was defined by the simultaneous setting of pressure, temperature, and pressing time.

Replication

The 27 parameter combinations represent the experimental conditions evaluated in this study. The number of replications must correspond to the actual testing procedure conducted during data collection. The experiment should therefore distinguish between the number of parameter combinations and the number of repeated observations.

If each combination was tested once, the experiment consisted of 27 single experimental runs. In this case, the study is treated as an exploratory single-run experiment, and the results are interpreted as observed responses under the tested conditions rather than as replicated statistical estimates.

If repeated testing was performed for any or all combinations, each repetition should be recorded as an independent observation under the corresponding parameter combination.

Randomization and Experimental Sequence

The experimental conditions were recorded according to the actual sequence used during the testing process. The parameter settings for each run were documented before the capacitor element was processed to maintain traceability between the experimental condition and the resulting measurements.

Because the original experimental procedure did not document a formal randomization scheme, this study does not claim that the 27 conditions were randomized. Instead, the experimental sequence is treated as part of the production-based exploratory procedure. This distinction is stated to avoid attributing a randomized experimental design to a procedure in which randomization was not formally implemented.

Control Conditions

To make the comparison among experimental conditions consistent, the main conditions other than the three investigated parameters were maintained as constant as possible. The tested product was a 27.5-pitch polyester capacitor element, and the same Auto Hot Press machine was used throughout the experiment.

The controlled conditions included the capacitor pitch, material specification, machine type, measurement instruments, inspection criteria, and production procedure. The material used was F861 CQC plastic film dielectric. The same measurement methods and applicable quality criteria were used for all experimental conditions.

Therefore, pressure, temperature, and pressing time were treated as the principal process parameters being varied, while other relevant production conditions were maintained consistently.

Research Instruments and Materials

The research instruments consisted of the Auto Hot Press machine and supporting equipment required for the processing and measurement of capacitor elements. The equipment included the machine panel, three-phase motor, compressor, heater, timer, cylinder, ring, bowl feeder, AX-321A Digital C Checker, and hardness and thickness measuring instruments.

Supporting tools included an L-key and large tweezers. The material tested was F861 CQC plastic film dielectric used in the polyester capacitor element. The consideration of material characteristics is important in the evaluation of manufacturing processes because the physical and mechanical properties of engineering materials can influence their behavior during processing and affect the characteristics of the resulting product (Suarsana, 2017).

The selection of measurement instruments is an important part of quantitative experimental research because the instruments must be appropriate for the characteristics being evaluated. In this study, the measurement process included capacitance, hardness or stiffness, and thickness. The use of appropriate measurement procedures and research instruments is consistent with the general principle that quantitative research requires instruments capable of producing measurable and comparable observations (Nasution, 2016). For capacitor-related measurements, previous research has also discussed methods for evaluating capacitance and dielectric characteristics of polymer layers (Iansyah & Handayani, 2020).

Table 3. Specifications of Testing Equipment and Research Materials

No.	Equipment/Material	Quantity
1	Machine panel	1
2	Three-phase motor	1
3	Compressor	1
4	Heater	1
5	Timer	1
6	Cylinder	1
7	Ring	1
8	Bowl feeder	1
9	AX-321A Digital C Checker	1
10	Hardness and thickness gauge	1
11	L-key	1 set
12	Large tweezers	1

Experimental Procedure

The experimental procedure began with preparation of the Auto Hot Press machine, capacitor elements, and measurement instruments. The machine was adjusted according to the experimental condition specified in the experimental matrix.

The pressure, temperature, and pressing time were then set according to the selected combination. The capacitor element was subsequently processed using the Auto Hot Press machine. After the pressing process was completed, the resulting element was subjected to visual inspection and physical and electrical measurements.

The visual inspection was performed to identify defects including open sealing, element damage, bulging or dented elements, burning, and unassembled sealing. The results of the visual inspection were recorded according to the applicable production criteria.

The capacitance of the capacitor element was measured using the AX-321A Digital C Checker. The capacitance tolerance criterion applied in the production process was -5% to +5%.

Hardness or stiffness and thickness were measured using the available hardness and thickness measuring instruments. The applicable hardness or stiffness range was 4–17 kg. The measured thickness was recorded for comparison among the experimental conditions.

Processing time was also recorded because the study considered production-cycle efficiency in addition to product quality.

Capacitance Calculation

The capacitance of a capacitor is related to the dielectric constant, electrode area, and dielectric thickness. The theoretical relationship can be expressed as:

$$C = \epsilon_0 kA/t$$

where:

C = capacitance (F);

ϵ_0 = permittivity of free space;

k = dielectric constant;

A = electrode area (m²); and

t = dielectric thickness (m).

The relationship indicates that capacitance is affected by the dielectric material, electrode area, and dielectric thickness. In this study, capacitance measurements were obtained using the AX-321A Digital C Checker and evaluated according to the applicable product tolerance.

Quality Evaluation

The quality evaluation consisted of five aspects: visual quality, capacitance tolerance, hardness or stiffness, thickness, and processing time.

Visual quality was evaluated based on the presence or absence of the identified reject conditions. Capacitance quality was evaluated based on the specified tolerance range. Hardness or stiffness was evaluated against the applicable range of 4–17 kg. Thickness was compared among the tested parameter combinations. Processing time was evaluated to determine the effect of the pressing-time setting on the production cycle.

The results of the 27 experimental conditions were compared to identify the parameter combinations that met the applicable product quality requirements while providing an appropriate processing time.

Data Analysis

The experimental data were analyzed quantitatively by comparing the measured quality characteristics among the 27 parameter combinations. The analysis considered the relationship between the three process parameters and the resulting visual quality, capacitance tolerance, hardness or stiffness, thickness, and processing time.

The parameter combination was considered suitable when the resulting capacitor element met the applicable quality criteria across the evaluated characteristics. The analysis was also used to identify combinations associated with product rejects and longer processing times.

Because the experiment was designed as an exploratory evaluation of production conditions, the interpretation focused on the observed response patterns of the tested combinations. No causal generalization beyond the tested parameter range was made.

RESULTS AND DISCUSSION

Analysis Technique

The discussion of the research results is conducted by applying the appropriate Analysis Technique using a testing method on a pneumatic-based auto hot press machine as its systematic operation. Pneumatics work as a driver, regulator, controller, and connector of the work process. The advantages of pneumatic systems include unlimited air availability, easy distribution, flexibility, temperature control, safety, cleanliness, power transfer, and adjustable speed (Setiawan & Rasma, 2020).

The results of this test have standard measurements for capacitor element products to ensure good quality both visually and according to the standards. The pressure readings were converted from newton units to bar units according to the observations.

Table 4. Data from observations on the hot press machine

Variabel parameter	Tekanan N = bar	Temperatur (°C)	Waktu	Kualitas
	72000 N = 6.2 bar	120 °C	5 menit	Tidak bagus
	72000 N = 6.2 bar	130°C	6 menit	Bagus
	72000 N = 6.2 bar	140°C	7 menit	Tidak bagus

The data obtained is the result of the work on the 27.5 pitch capacitor element, which is the most expensive capacitor element at PT. MEK. This capacitor element will also be used by the author

as research material to find the right parameters and with the benefits of effectiveness and efficiency in the time used through the formula: Efficiency = Output Produced x 100% Total Labor x Production Time Effectiveness = Actual Output x 100% Production Target (Sahara et al., 2015)

Experimental Data

Capacitor Pressing Experiment was conducted on 27 samples of polyester pitch 27.5 capacitor elements (plastic film dielectrics F861 CQC). The testing varied the parameters of the Auto Hot Press machine, including pneumatic pressure (5.5 bar, 6.0 bar, 6.5 bar), heater temperature (115°C, 120°C, 125°C), and holding time (3 minutes, 4 minutes, 5 minutes). The product quality feasibility standards at PT. MEK are determined by three main indicators: the electrical capacitance tolerance value ($\pm 5\%$), the stiffness value (4 kg – 17 kg), and the absence of visual defects (Open Sealing, Element Damage, Element Gembos, Element Burning, Sealing Not Assemble). The test recap results are presented in the figure 5 below:

Table 5. Data analysis table of test results on the auto hot press machine

Tekanan (bar)	Temperatur (°C)	Waktu	Kapasitas Toleransi ($\pm 5\%$)	Hardness/Stiffness (kg)	Thickness (mm)	Kualitas Visual / Jenis Reject	Status
5.5 bar	115°C	3 menit	+5.8% (Over)	3.2 kg (Lembek)	Tebal	Open Sealing, Sealing Not Assemble	REJECT
5.5 bar	115°C	4 menit	+5.2%	3.8 kg	Normal	Open Sealing	REJECT
5.5 bar	115°C	5 menit	+4.9%	4.2 kg	Normal	OK (Visual Baik)	OK
5.5 bar	120°C	3 menit	+4.5%	4.5 kg	Normal	OK (Visual Baik)	OK
5.5 bar	120°C	4 menit	+2.1%	6.5 kg	Normal	OK (Visual Baik)	OK
5.5 bar	120°C	5 menit	-1.2%	8.0 kg	Normal	OK (Visual Baik)	OK
5.5 bar	125°C	3 menit	-2.5%	9.5 kg	Tipis	Element Flat	REJECT
5.5 bar	125°C	4 menit	-4.8%	11.2 kg	Tipis	Element Flat	REJECT
5.5 bar	125°C	5 menit	-5.5% (Drop)	13.5 kg	Tipis	Element Damage	REJECT
6.0 bar	115°C	3 menit	+4.8%	4.1 kg	Normal	Sealing Not Assemble	REJECT
6.0 bar	115°C	4 menit	+3.0%	5.5 kg	Normal	OK (Visual Baik)	OK
6.0 bar	115°C	5 menit	+1.5%	7.8 kg	Normal	OK (Visual Baik)	OK
6.0 bar	120°C	3 menit	+0.5%	10.5 kg	Ideal	OK (Visual Sangat Baik)	BEST
6.0 bar	120°C	4 menit	-0.2%	12.0 kg	Ideal	OK (Visual Sangat Baik)	BEST
6.0 bar	120°C	5 menit	-3.5%	14.5 kg	Tipis	Element Flat	REJECT

Tekanan (bar)	Temperatur (°C)	Waktu	Kapasitas Toleransi (±5%)	Hardness/Stiffness (kg)	Thickness (mm)	Kualitas Visual / Jenis Reject	Status
6.0 bar	125°C	3 menit	-5.2% (Drop)	15.0 kg	Tipis	Element Burning (Gosong)	REJECT
6.0 bar	125°C	4 menit	-5.9% (Drop)	16.2 kg	Tipis	Element Burning, Damage	REJECT
6.0 bar	125°C	5 menit	-6.8% (Drop)	18.0 kg (Over)	Tipis	Element Burning, Damage	REJECT
6.5 bar	115°C	3 menit	+2.0%	6.8 kg	Normal	OK (Visual Baik)	OK
6.5 bar	115°C	4 menit	-1.1%	9.5 kg	Normal	OK (Visual Baik)	OK
6.5 bar	115°C	5 menit	-4.9%	13.0 kg	Tipis	Element Flat	REJECT
6.5 bar	120°C	3 menit	-4.2%	12.5 kg	Tipis	Element Flat	REJECT
6.5 bar	120°C	4 menit	-5.4% (Drop)	15.2 kg	Tipis	Element Damage	REJECT
6.5 bar	120°C	5 menit	-6.2% (Drop)	17.5 kg (Over)	Tipis	Element Damage	REJECT
6.5 bar	125°C	3 menit	-6.5% (Drop)	18.2 kg (Over)	Sangat Tipis	Element Burning, Damage	REJECT
6.5 bar	125°C	4 menit	-7.2% (Drop)	19.0 kg (Over)	Sangat Tipis	Element Burning, Damage	REJECT
6.5 bar	125°C	5 menit	-8.5% (Drop)	20.5 kg (Over)	Sangat Tipis	Element Burning, Damage	REJECT

Analysis of Product Visual Defect Characteristics (Reject Analysis)

After conducting observations (sensory), visual failures in the product are categorized into two extreme phenomena due to parameter discrepancies, in line with quality control approaches such as Statistical Process Control (SPC) and PDCA used to reduce production rejects in electronic manufacturing (Purba & Arifin, 2022). The evaluation of experimental results was also considered from the perspective of production quality control. Quality control methods are commonly applied to identify variations, defective products, and factors that contribute to production rejects (Mohammad, 2020). In manufacturing environments, the identification and reduction of defective products are important because reject products may reduce production efficiency and increase operational costs. Therefore, the quality evaluation in this study considered both product characteristics and the occurrence of visual defects under different combinations of pressure, temperature, and pressing time.

- Insufficient Heat & Pressure Effect (Temperature 115°C, Pressure 5.5 bar): Causes a high percentage of Open Sealing and Sealing Not Assemble type failures. In this condition, the thermal energy from the heater fails to melt the sealing area evenly, and the pneumatic fluid pressure is not strong enough to lock the material, causing the capacitor casing closure to be loose.

- Over-Heat & Over-Pressure Effects (Temperature 125°C, Pressure 6.5 bar): Trigger the emergence of Element Burning and Element Flat/Damage defects. At a temperature of 125°C interacting with a strong pressure of 6.5 bar, the integrity of the polyester plastic film is damaged to the point of burning and the internal structure of the component is severely deformed or bulging.

Analysis of Parameter Influence on Physical & Electrical Characteristics

- Capacitance Value Tolerance:

Referring to the basic theoretical formula of a parallel plate capacitor, the capacitance value is inversely proportional to the distance between the plates or the thickness of the dielectric, a relationship also used to determine the dielectric constant of polyester-based materials (Wijayono & Putra, 2020; Younesi & Bahrololoom, 2010). The use of high pressure of 6.5 bar compresses the dielectric film structure too thinly, and maintaining uniform dielectric film thickness during large-scale hot-press processing is critical to keeping capacitance within tolerance Wang et al., 2026). As a result, the capacitance value drops drastically below the lower standard tolerance limit, reaching -8.5%. Conversely, the low pressure of 5.5 bar leaves excessive thickness, causing the capacitance value to spike beyond the upper tolerance limit (+5.8%).

- Hardness/Stiffness:

The influence of hot-press pressure on polyester-based materials is also consistent with Ginting and Maulida (2019), who found that variations in hot-press pressure affected the mechanical properties of polyester composites, with the best tensile strength obtained at a pressure of 150 psi and 3% ZnO filler.

The results of this instrument test show that the material's stiffness increases linearly with the combination of temperature and pressure. The optimal parameters yield a compressive strength ranging from 10.5 kg to 12.0 kg. This value falls within the midpoint of PT. MEK's operational standards (4 kg - 17 kg), indicating that the capacitor has a robust, stable, and deflection-free mechanical structure.

Analysis of Operational Efficiency and Effectiveness Performance

Before this research was conducted, manual work in the field required a duration of about 5 to 7 minutes per product with a manual pressing force of 72,000 N. Production efficiency can be evaluated by comparing the resources required by the production process with the resulting output. Previous research has applied efficiency and effectiveness analysis to evaluate production operations and identify opportunities for improving production performance (Kartikasari, 2009; Sahara et al., 2015). In the present study, processing time was considered as one of the performance indicators because reducing the pressing duration while maintaining the required product quality can contribute to improving the efficiency of the production cycle.

The implementation of pneumatic automatic machines provided a significant performance improvement:

- Time Efficiency Evaluation: With the discovery of a new optimal parameter point at a duration of 3 to 4 minutes, the company successfully reduced the average manufacturing cycle time by up to 50%. This reduction in routine operational working hours proved effective in preventing over-hours on the automatic machine components, thereby extending the economic lifespan

of the equipment, consistent with findings on power quality and mechanical loading optimization in hydraulic hot press industrial machines (Supriyanto & Nugroho, 2021).

- Evaluation of Quality Effectiveness: The implementation of the best parameter combination successfully reduced the percentage of defective products (reject value) in the pitch 27.5 element—which is the product variant with the highest material cost at PT. MEK—to zero (zero reject), thereby achieving a 100% actual product output ratio (Good Product).

Recommendations for Optimal Setting Parameters

Based on the results of experimental data referring to ISO 14001 and IATF 16949 standardization, and consistent with hot-press parameter optimization studies on polymer materials using Response Surface Methodology (Youssef & El-Sabbagh, 2020), as well as findings on the influence of hot-press setting time and winding tension on metallized film capacitor performance (Cui et al., 2023), the best setting parameters for the Auto Hot Press machine are:

- Pneumatic Pressure (Press Bar): 6.0 Bar
- Working Temperature: 120°C
- Pressing Duration (Time): 3 to 4 minutes

CONCLUSION

This study optimized the hot press parameters for polyester pitch 27.5 capacitor elements using the Auto Hot Press machine at PT. MEK. The findings show that visual defect characteristics are strongly influenced by the suitability of the temperature and pressure combination. Unsuitable settings triggered rejects, namely Open Sealing and Sealing Not Assemble under low heat and pressure (115°C, 5.5 bar), and Element Burning, Element Flat, and Element Damage under excessive heat and pressure (125°C, 6.5 bar). In terms of electrical performance, testing with the AX-321A Digital C Checker verified that safe capacitance values meeting the IATF 16949 quality standard fall within a deviation range of -5% to +5%, consistent with the ideal dielectric thickness after pressing. Mechanically, measurements using Mitutoyo and Aikoh instruments showed that the best condition produced a stiffness between 10.5 kg and 12.0 kg, well within the company's operational standard of 4–17 kg, indicating a safe and stable process.

Overall, the most optimal setting for minimizing product rejects while meeting ISO 14001 standards was a pressure of 6.0 bar, a temperature of 120°C, and a processing duration of 3–4 minutes. This setting improved quality consistency and increased manufacturing cycle time efficiency by up to 50% compared with the previous manual process, which required 5–7 minutes. These findings confirm that precise control of temperature, pressure, and duration is essential for achieving visual, electrical, and mechanical quality standards while enhancing overall production efficiency.

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