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The Effect of Temperature on Sealer Adhesion in the Packaging Process using the KM-2500 Machine

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Abstract

This study evaluates the effect of temperature on the adhesion of packaging in the KM-2500 sealer machine. Leaks, imprecise seals, and rework often disrupt the packaging process. This research focuses on temperature tests of two subsystems: roller sealers and end sealers. The operating speed is set at 150 rpm, the vacuum pressure is 0.6 bar, and the stabilization time is 15 minutes. The packaging material is an aluminum foil laminate with an LDPE seal layer. Temperature measurements are carried out using thermocouples. The quality of the adhesive is assessed through visual inspection and a simple leak test. Five sets of temperature points were tested on each subsystem. The results showed that the temperature was too low, resulting in weak adhesion and leakage. Too high a temperature creates thermal distortion in the film. Optimum conditions were obtained on a 259 °C Roller Sealer and a 134 °C End Sealer with a 100% success rate on two replications. These findings confirm that temperature is the primary controlling parameter for seal quality. Operating recommendations include 15-minute pre-heating, in-line temperature verification, and periodic monitoring of seal quality. These results can serve as a reference for establishing standard settings on production lines to minimize scrap and rework.

Keywords: Heat sealing, Roller sealer, End sealer, Seal integrity.

1. Introduction

A company in North Sumatra produces biscuits and snacks on a large scale. The quality of the packaging has a significant impact on the safety of the product and the brand's image in a competitive market [1-3]. Good packaging protects the taste, texture, and shelf life of the product for the consumer, ensuring a consistent experience [4-6]. Any minor defect in the seal can lead to customer complaints and quality claims [7-8]. Therefore, the control of the packaging process must be consistent and documented.

On the KM-2500 line, the problems that often arise are leaks, imprecise seals, and repeated rework. The root of the problem is usually related to inconsistent temperature settings on the roller sealer and end sealer [9-11]. Slight temperature variations can change the fusion behavior of the thermoplastic layer. This condition is exacerbated by changes in load, material variation, and temperature sensor drift. The impact includes machine shutdown, increased scrap, and additional inspection costs [12-13]. Productivity decreases, while quality stability is difficult to maintain from shift to shift.

The packaging material used is aluminum foil lamination with an LDPE seal layer [14]. This material requires a specific temperature range to achieve a strong interface bond. Pressure, film pull speed, and contact time all affect the results [15]. The four parameters interact with each other so that the setting of one variable should not stand alone. In practice, operators often adjust temperatures to pursue production targets. Data-based adjustments risk pushing the process out of safe limits. A scientific basis is needed so that the setting is not based on trial and error [16].

The plant faces a gap due to the absence of a clear operating map for the current machine-material combination [17]. Historical data is scattered and not standardized. There is no measurable baseline that binds the temperature of roller sealers and end sealers to seal quality outputs [18]. As a result, quality control depends on the final visual inspection. This approach is reactive and resource-intensive. Concise, measurable, and replicable experimental studies are required. The results of the study are expected to serve as a reference for establishing a resilient standard against normal variations in the process.

This study assessed the effect of temperature on adhesion in KM-2500 with other parameters controlled. The speed is maintained at 150 rpm and the vacuum pressure at 0.6 bar. The thermal stabilization time is set 15 minutes before the test. Five temperature points are tested on the roller sealer and end sealer. The quality of the adhesive is evaluated through visual inspection and a simple leak test. The best results will be set as the reference setting on the line.

The purpose of the study was to establish a safe and stable working temperature window for KM-2500. The research also aims to reduce scrap and rework through data-driven setting standards. The next goal is to compile operational recommendations on pre-heating and in-line temperature verification. Finally, the research provides a foundation for quality documentation that is easy to audit and train operators. Thus, the quality of the packaging can be consistent, and the failure cost can be reduced.

Thermally mathematically calculated by:

$$Q = m.C_p.\Delta T \quad (1)$$

$$H = \frac{Q}{t} = \frac{kA.\Delta T}{L} \quad (2)$$

2. Methods

The test was carried out on the KM-2500 with two subsystems (Table 1), a roller sealer and an end sealer. The operating speed of 150 rpm and the vacuum of 0.6 bar are kept constant. The thermal stabilization (preheat) time is set 15 minutes before data collection.

Packaging material. Laminate aluminum foil with LDPE coating as a fusion medium. Instruments. Thermocouple for sealer point monitoring and a thermocouple for surface verification.

Table 1. Experimental test matrix for the KM-2500 heat-sealing process

Subsystem	Temperature setpoint (°C)	Replications (n)	Fixed speed (rpm)	Vacuum pressure (bar)	Thermal stabilization (min)	Acceptance criterion
Roller Sealer	244	2	150	0.6	15	No leakage; neat and continuous seal
Roller Sealer	249	2	150	0.6	15	No leakage; neat and continuous seal
Roller Sealer	254	2	150	0.6	15	No leakage; neat and continuous seal

Subsystem	Temperature setpoint (°C)	Replications (n)	Fixed speed (rpm)	Vacuum pressure (bar)	Thermal stabilization (min)	Acceptance criterion
Roller Sealer	259	2	150	0.6	15	No leakage; neat and continuous seal
Roller Sealer	264	2	150	0.6	15	No leakage; neat and continuous seal
End Sealer	124	2	150	0.6	15	No leakage; neat and continuous seal
End Sealer	129	2	150	0.6	15	No leakage; neat and continuous seal
End Sealer	134	2	150	0.6	15	No leakage; neat and continuous seal
End Sealer	139	2	150	0.6	15	No leakage; neat and continuous seal
End Sealer	144	2	150	0.6	15	No leakage; neat and continuous seal

3. Results and Discussion

The engine is heated for 15 minutes until the setpoint temperature is stable, as shown in Table 2. The product is inserted, then the seal is formed as the film passes through the roller sealer and end sealer. The actual contact time is on the order of seconds, while 15 minutes is the thermal stabilization time. Temperatures of 244–254 °C result in weak adhesions and leakage. The temperature of 259 °C provides a neat and leak-free seal. A temperature of 264 °C poses a risk of film distortion in some samples (Table 2).

Temperatures of 124–129 °C are not sufficient for LDPE layer fusion. A temperature of 134 °C consistently provides a leak-free seal. Temperatures of 139–144 °C increase the risk of heat stains on the film (Table 3).

Table 2. Roller sealer temperature test matrix (fixed speed 150 rpm, vacuum 0.6 bar)

No.	Temperature (°C)	Trial	Stabilization Time (min)	Seal Result
1	244	1	15	Leak, weak adhesion
2	249	2	15	Leak, weak adhesion
3	254	3	15	Leak, weak adhesion
4	259	4	15	Good, no leakage
5	264	5	15	Good adhesion, risk of distortion

Table 3. End sealer temperature test matrix (fixed speed 150 rpm, vacuum 0.6 bar)

No.	Temperature (°C)	Trial	Stabilization Time (min)	Seal Result
1	124	1	15	Leak, weak adhesion
2	129	2	15	Leak, weak adhesion
3	134	3	15	Good, no leakage
4	139	4	15	Good, heat marks observed
5	144	5	15	Good, heat marks observed

The combination of 259 °C (Roller Sealer) and 134 °C (End Sealer) gives 100% success on two replications. This setting strikes a balance between the need for fusion and the prevention of distortion. Temperature stability is the key to seal quality (Table 4).

Table 4. Combined process–response mapping

No.	Roller–End Temp (°C)	Stabilization Time (min)	Overall Outcome
1	244 – 124	15	Not acceptable: leak
2	249 – 129	15	Not acceptable: leak
3	254 – 139	15	Marginal: minor leak
4	259 – 134	15	Acceptable: good, no leak
5	264 – 144	15	Acceptable, minor heat imprint

Table 5. Replication check (normality screening by repetition count)

No.	Roller–End Temp (°C)	Stabilization Time (min)	Rep-1	Rep-2
1	244 – 124	15	1	1
2	249 – 129	15	1	1
3	254 – 139	15	1	1
4	259 – 134	15	1	1
5	264 – 144	15	1	1

Table 6. Summary of best-performing condition

Parameter	Best Setting
Roller Sealer Temperature	259 °C
End Sealer Temperature	134 °C
Speed / Vacuum	150 rpm / 0.6 bar
Thermal Stabilization	15 min
Outcome	100% pass in two replications

Figure 1. The curve illustrates the seal quality score against the roller sealer temperature. Temperatures of 244–254 °C result in a zero score due to weak and leaky seals. A sharp rise occurred at 259 °C with a score of two, which signifies a neat seal with no leakage. A drop in score at 264 °C indicates a risk of distortion or heat traces on the film. These results confirm the existence of the fusion threshold temperature of the LDPE layer on the roller. Precision control at approximately 259 °C is crucial for maintaining process quality and consistency.

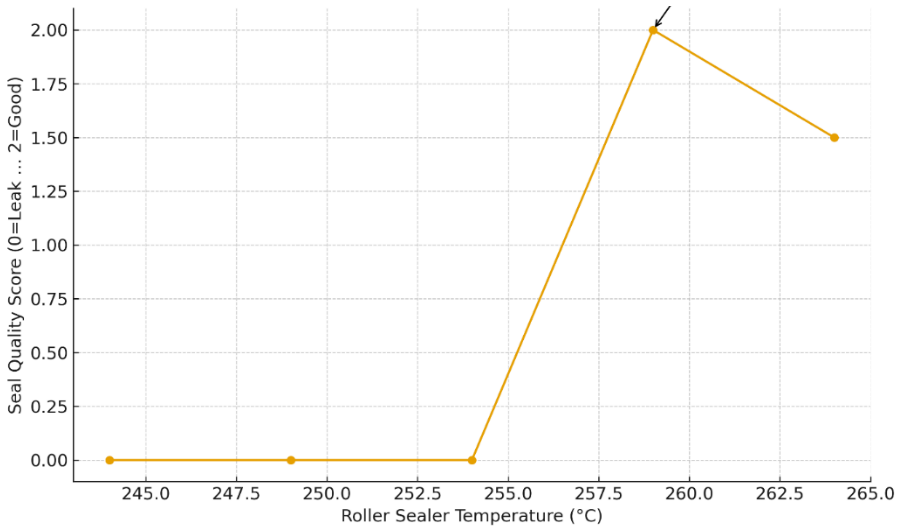

Figure 1. Seal quality score across roller sealer temperature

Figure 2. The pattern on the end sealer is in line with the roller, but the window is narrower. Temperatures of 124–129 °C have not yet reached fusion, so the seal leaks. The temperature of 134 °C gives it a double score and the best quality. An increase to 139–144 °C

creates a trace of heat even though the seal appears strong. This indicates high sensitivity due to the local heat concentration in the final blade. Set point 134°C needs strict control limits with in-line verification.

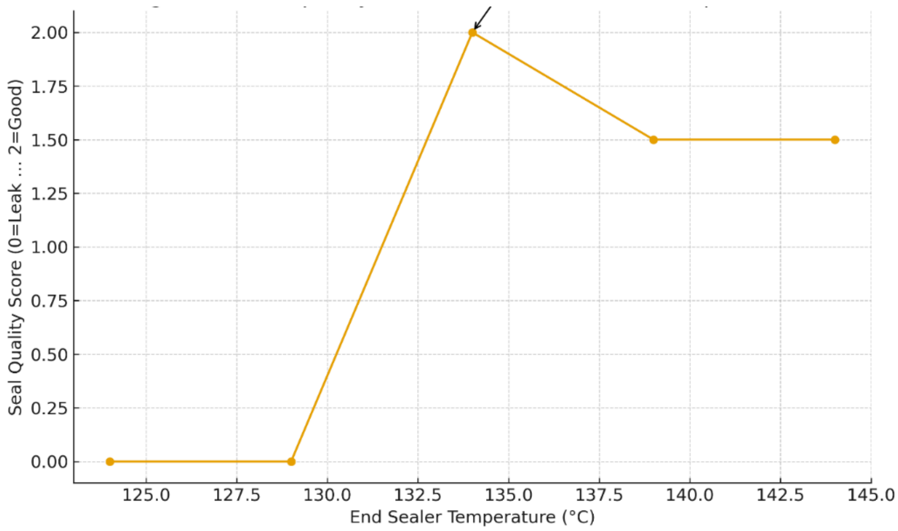

Figure 2. Seal quality score across roller sealer end temperature

Figure 3. A process–response map visualizes the interaction of roller and end sealer temperatures. The combination of low (244–124 °C) and (249–129 °C) results in an unsuitable category. Intermediate combinations (254–139 °C) are still marginal with light leakage. The safe zone appears clear at 259–134 °C with sound output without leakage. The combination of high (264–144 °C) temperatures adds a trace of heat even though the seal is attached. This map highlights the narrow operating window, as well as the need for documented temperature recipes.

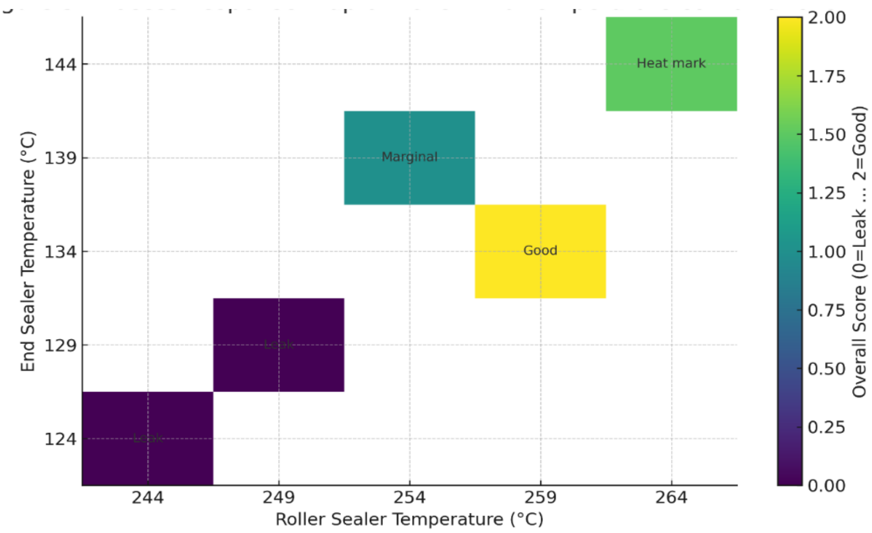

Figure 3. Process -response map of roller-end temperature combinations

Figure 4. The distribution of the defect mode on the roller confirms the gradual transition of the defect. Three sets of low temperature points consistently give rise to "leak, weak adhesion". The 259°C point set switched to "good, no leakage" on two replications. The 264°C point set shifts to "heat observed marks" marking over-seal. This pattern shows an "inverted U" quality curve to temperature. The peak quality point is at 259 °C with the lowest risk of scrap.

Figure 5. The defect distribution in the end sealer exhibits similar but more sensitive behavior. Temperatures of 124 and 129 °C are constantly leaking because the fusion energy is not sufficient. The temperature of 134 °C was consistent well on the two replications. A rise to

139–144 °C creates a heat trail that disrupts the packaging's aesthetic appeal. Because of this, end sealers require a tighter temperature tolerance than rollers. A reset is mandatory when there is a change in the material or thickness of the film.

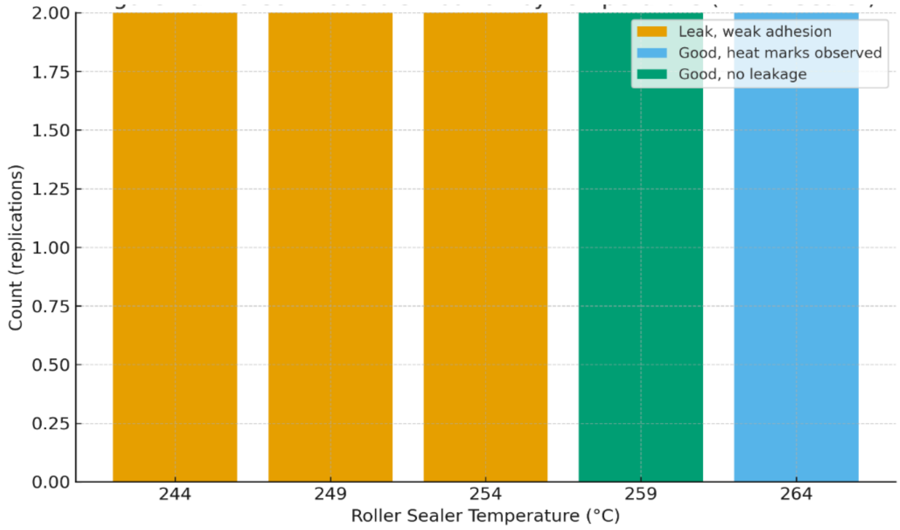

Figure 4. Defect-mode distribution by temperature (roller sealer)

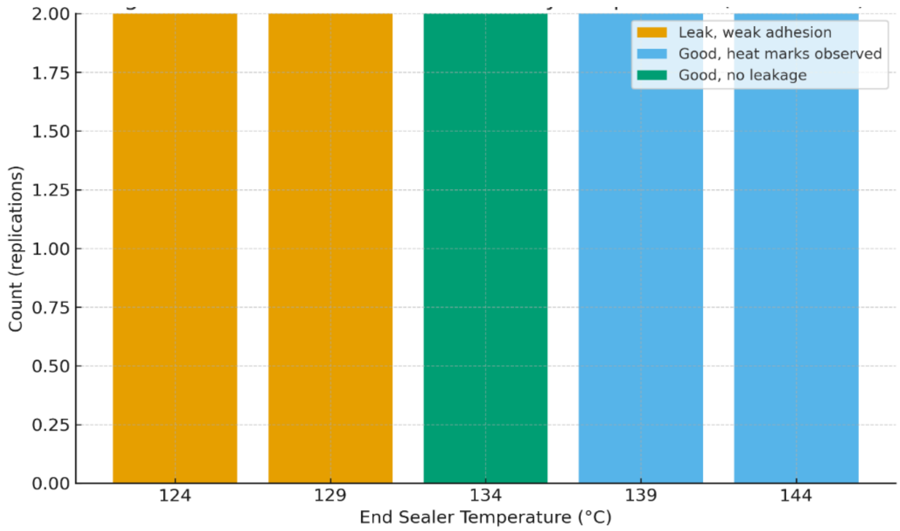

Figure 5. Defect-mode distribution by temperature (end sealer)

Synthesis and implications of the process. The five graphs conclude that temperature is the primary determinant of seal integrity. The safest operating points are 259°C for rollers and 134°C for end sealers. 15-minute pre-heat helps stabilize the set point before production. Prescription-based controls, temperature logging, and periodic audits will hold the process within a secure window. This approach reduces rework, maintains product aesthetics, and extends its shelf life.

4. Conclusion

Temperature proved to be the primary determinant of seal integrity on the KM-2500. Low temperatures, at 244–254 °C, trigger weak seals and leaks in rollers. Low temperatures at 124–129 °C give the same symptoms—the increase in temperature to 259 °C on the roller results in a neat seal without leaking. The temperature of 134 °C at the end provides the best quality and stability. The rise above it generates a trace of heat in the film. It flags oversealed conditions and the risk of distortion. The combination of 259°C (roller) and 134°C (end) makes for a safe operating window. A speed of 150 rpm and a vacuum of 0.6 bar support process consistency. 15-

minute pre-heat maintains the stability of the set point before production. Two replications show a 100% graduation rate under optimal conditions. End sealers are more sensitive to temperature deviations. The visual evidence of the five figures is consistent between subsystems. These findings are worthy of being used as a standard baseline for current laminated materials. The operational impact is that scrap decreases and rework decreases. The visual quality and integrity of the seal are improved at the scale of the line.

Set points of 259 °C on the roller and 134 °C on the end provide stable and uniform operation. A 15-minute pre-heat, along with in-line temperature verification, keeps the set point consistent. Automatic temperature recording with alarms provides good traceability and early response to deviations. The end sealer consistently meets quality standards within the ±2°C range, while weekly sensor calibration ensures accurate measurements. Statistical monitoring via X-bar/R control cards and documented action limits accelerates process recovery. SOP changeover and re-validation per lot maintain suitability when materials or thickness change. Operator competence, preventive maintenance, leak tests, and peel strength tests strengthen quality assurance, while DOE–RSM-based follow-up studies and KPI (first-pass yield, leak rate, rework, energy per pack) monitoring support continuous improvement.

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