Failure analysis and improvement of heat sealing testing method

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Abstract: In Thailand, the major cause of heat sealing problem is that temperature at the interface surface of material is not monitored and controlled appropriately. Conventional testing method of seal strength ASTM F88-07 and JIS Z0238 are extensively used in industries and researches. Conventional method use wide temperature pitch for heat sealing. The variation of heat seal strength of conventional method is very high because to temperature traceability use only display from heat sealing machine. With the innovative method, temperature of melting surface is monitored and controlled directly. In this study, the step of heating temperature for heat seal strength testing is 1-2°C for obtaining details of heat seal strength. Temperature measurement and display were calibrated before applying heat sealing process. The differences from the convention method and proposed method are discussed. The objectives of this research are as follows. Firstly, investigation of trouble section in conventional testing method. Secondly, the new test method for high accuracy of heat seal sample. Experiments are conducted to prove the superiority of new proposed method.

Keywords: heat seal; heat seal strength; peel seal; tear seal; temperature at interface; MTMS; temperature traceability

1. Introduction
1.1. Social background and demand of heat seal technique
Thermoplastic material has been developed since half century. It is widely used for variety of packages for foods, snacks, medical products, daily products such as toiletry, soap, shampoo, and including electronic parts etc. because of its properties such as heatsealability, printability, light protection, oxygen barrier, odor barrier, and low cost. Therefore, thermoplastic packaging is indispensable for everybody in daily life.

Heat sealing is a successful development of polymer material area in 20th century. Heat seal is a technique of thermally bonding of thermoplastic film together by the heating and cooling process. Today, many consumers concern about easy opening and safety from flexible packages. Also, the product inside the package should not go off from tearing force and product spilling during tearing it. Another requirement is furnishing of heat seal surface area or reseal after peeling the package. Some customers need neat and tidy seal area after peeling it to reseal or roll up for the next consumption. With above reasons, they need the manufacturers improve their products more convenient.

1.2. Problem of conventional heat seal technique
Heat seal strength is used to measure the bonding strength of thermoplastic material. Conventionally, there are two standards related with heat seal strength. ASTM F88-07 and their references, and JIS Z 0238 are widely used in Japanese manufacturers. [1,2] The content of ASTM F88-07 recommends about standard test method for heat seal strength. The content of JIS Z0238 is similar F88 but there is more information about testing completed packages. Both standards only suggest guide line for heat seal strength measurement. In addition, ASTM F2029 is a guide line for determination of heatsealability of flexible web as measured by heat seal strength. [3] However, this standard is not very much utilized in industry.

Many heat sealing’s stakeholders in Thailand, such as material manufacturers, machinery manufacturers, operation manufacturers, packaging testing laboratories, and customers deal with heat sealing problems. From the
investigation of the voice of stakeholder in Thailand, the major problem is that temperature of melting surface is not controlled. To eliminate such problems, it needs to control temperature at the melting surface between heat seal area of both materials. Two mentioned standards could not guarantee the mentioned problems as above. Finally, the customers face with many heat sealing problems. Temperature control of melting surface needs improvement.

The objectives of this research are as follows. Firstly, it is to present heat sealing problems in Thailand. Secondly, it is to demonstrate the application of new technique for heat sealing. Thirdly, it is to propose new method for heat sealing quality management.

1.2.1. There is no standard which becomes the dependence.

1) Large companies apply ASTM F88 standard. Many material and product manufacturers apply ASTM F88 standard to certify their products to the customers.

2) Many companies do not applied ASTM F88 standard. However, they could not guarantee the quality of product and the customer satisfaction. For example, the packaging machinery companies in Thailand do not apply ASTM F88 standard to the food company or the operation company.

3) Trial and error method. If the operation companies could not understand any standard, they will ask information from material company and machinery companies. If there is no the right answer, the operation company will use trial and error method by adjusting heat seal “Wrong” parameter; temperature, time, and pressure. Finally, they use high temperature high pressure for testing their products that depends on the intuition.

4) Some companies, the standards are controlled by head office in other countries. (Japan, USA, and European company) Some food company in Thailand is controlled by the head office in abroad country. They used the regulation, policy, and result of testing method from the head office for themselves.

5) Some companies need testing services from local testing laboratory. The company who do not have own laboratory for testing. They send the sample to testing laboratory. Testing laboratory also apply ASTM F88 to the testing.

6) Some companies are supported by packaging machinery, and material company. Operation companies may ask supporting from packaging machinery companies, consultant companies, and packaging material companies. They could not get the right answer to improve heat sealing to their product.

1.2.2. The problems of heat seal condition of

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1) Some companies want to control peel sealing perfectly. For example, snack or food companies need to apply easy peel to their products. However, it is difficult for them to apply easy peel to their product.

2) Many companies face with difficulty in control temperature because many companies control only temperature of heating block.

3) Many companies face with difficulty in pressure and time control. Many manufacturers check pressure by torque wrench. Heating time is adjusted by trial and error method depending on the operator intuition.

4) Though, many companies apply ASTM, some companies do not rely on ASTM method due to results of heat sealing measurement is not reliable. The variation of heat seal strength is very wide. There is no explanation and suggestion of the problems for the company.

5) Temperature control for packaging function is not considered correctly. Packaging functions should balance between opening/peeling function and closing/completed function of packaging. ASTM standard recommend that the package should balance between both function. However, there is no explanation of method for balance the functions.

6) Temperature control for material abilities is not confirmed. Material abilities, such as peel seal range, peel seal strength, could not utilize. There are no tools for checking material abilities. The important information of material abilities that should be investigated are such as peel seal range, and peel seal strength.

![Figure 1. Relationship between heating temperature and expression of the tensile strength of heat sealing](image)

1.3. Methodology of heat sealing technique

The consideration of coexistence of packaging function between easy open and tight closing is very important for customers, however there is no indication for testing of
such functions in ASTM F88-07 standard. Thus, customers still face difficulty in easy open of the seal-tight packages. There is no suggestion about selection of packaging function in ASTM F88-07. Due to none technology supports such requirements for stakeholders and consumers in the past. Heating temperature is confirmed as the most important factor for controlling heat seal strength. The relationship between heating temperature and heat seal strength is shown in figure 1. [4] In the standard method of conventional tensile test F88-07 and heating method F2029, it cannot obtain right heat sealing characteristic of the materials because conventional testing of heat sealing depends on temperature of heating blocks. This section proposes new testing method related to heating temperature corresponded with heat seal strength are shown in figure 2a. All testing methods for temperature measurement as shown in figure 2a require accurate parameters. Conventional testing items related to heat seal strength is shown in figure 2b. These testing methods in Figure 2 are used to improve high reliable heat seal strength characteristic. Testing method for heat seal strength in figure 2a is the most important testing in this research which relate to testing item in figure 2b e.g. seal strength, bursting, falling, pressure resistance, and leakage. All testing items in this standard relates to heat seal strength. However, the conventional standard does not clarify clearly the relationship among items together to seal strength. In case of high elongation failure mode of material, seal strength can be deviated by the stress/strain property of material. Sample can be reinforced with backing with tape or using dumbbell-shape sample. [5]

Conventional method controls temperature at heating blocks or heat jaws rather than temperature at the interface of material or melting surface temperature. Also, Heat conductance of materials is different. Real temperature of the heat jaws of different machines is different. Hence, it is impossible to control temperature of the machine in the same temperature.

1.5 Correct definition of three elements of heat sealing

It is widely known that temperature, time, and pressure are the critical factors for heat sealing process. Temperature regulation is the main control element referred to "melting temperature" of sealant material. [6] However, adjusting temperature of heating block has used all over the world for several decade year. Verification of heat sealing can be done by consider heat seal strength corresponding to heating temperature and observe failure mode of samples. However, above mentioned problems can not solve successfully. In order to solve such problems, it is necessary to measure and control temperature at the interface of material.

1.6. Innovative test method of heat sealing performance of completed product

Many stakeholders apply the conventional testing method; however they still have problems of heat sealing as mentioned in the previous section. This section proposes the conventional method comparing with new improvement method of evaluation of heat sealing performance of the completed package. [7]

1.7. Measuring method for Temperature of Melting Surface (MTMS)

MTMS, high reliability testing method, is developed by Hishinuma. [8-11] In this research, MTMS is conducted and compared to the conventional testing method. Heat jaw method for heat sealing process is widely used in manufacturing and laboratory. In heat jaw method, the temperature is high significant parameter for
heat seal process. In conventional method, temperature of heating block is controlled by temperature controller which is measure temperature from the sensor of heating jaws. It is impossible to measure and control temperature of melting surface. In MTMS system, thermocouple is inserted between the interface of material in order to measure and analyze changes in real time response. Temperature can be monitor from the surface of heating block and be controlled by high accuracy temperature controller. The comparison between conventional temperature control and MTMS system is shown in figure 3.

![Figure 3. Comparison between conventional method and MTMS](image)

The advantage of MTMS is it measure temperature of melting surface in real time. The main feature of MTMS is that it direct measure the small area of melting surface and measure the surface temperature of heating jaws to control the temperature of melting surface more precisely. The schematic diagram of MTMS model and equivalent RC lumped-electrical circuit of heat transfer refer to [12] The reasons of temperature could not controlled with high precision as the required temperature are following reasons: 1) Accuracy of the sensor, 2) Heat capacity of the sensor, 3) Heat radiation between heating jaws, 4) Heat radiation between machine structures, 5) Performance of the controller, 6) Heat conduction from heating block through the body the structure or the body of the heat sealing machine, 7) Installation Heat Pipe, 8) Temperature controller.

2. Experiments

In this section, some experiments are demonstrated to exhibit heat seal problems. PE bag (PE/75), which is widely used in the local market, is conducted in these experiments. The results of the experiment are compared with different standards and methods. The application of this PE film is general purpose PE bag. Many factors related to temperature control are heating area, heat seal area cutting, position of sample on heat jaws, types of material such as easy peel material etc. The experiments for confirmation of variation of seal strength are prepared as methodology following: Step 1 Selection of the testing material, Step 2 The estimation of the expected functions of the heat sealing, Step 3 Selection the testing requirement, Step 4 Prepare of the sample, Step 5 Tensile testing. The samples were prepared in different ways as shown in table 2.

<table>
<thead>
<tr>
<th>Testing condition</th>
<th>Sample 1</th>
<th>Sample 2</th>
<th>Sample 3</th>
<th>Sample 4</th>
<th>Sample 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Heat sealing machine</td>
<td>General double side heat sealing machine</td>
<td>Lago SL-2</td>
<td>MTMS M-0808</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) Location of Temperature sensor</td>
<td>Heating block</td>
<td>Heating block</td>
<td>Between surface of material and surface of heating block</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3) Temperature traceability</td>
<td>Display of digital controller</td>
<td>Display of digital controller</td>
<td>Calibrated digital thermometer, Display of digital controller, and Display of surface of heating block sensor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4) Heating time</td>
<td>3 Sec selected by intuition</td>
<td>1 Sec selected by intuition</td>
<td>Calculated from temperature response of material</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5) Starting /ending temperature</td>
<td>Trial and error</td>
<td>Based on melting point of material</td>
<td>Based on standard heat seal strength[13]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5) Pressure on specimen</td>
<td>selected by intuition</td>
<td>0.1MPa by air cylinder of machine</td>
<td>0.2 MPa on specimen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6) Temperature incremental step</td>
<td>5-10°C</td>
<td>2.5°C</td>
<td>1-2°C within peel seal zone, 5-10°C in tear seal zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7) No. of specimens</td>
<td>10 specimens</td>
<td>10 specimens</td>
<td>3 specimens</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8) Types of surface</td>
<td>Flat</td>
<td>Knurling</td>
<td>Flat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9) Shape, dimension, and supporting of specimen</td>
<td>Rectangular ASTM F88 (Regular type)</td>
<td>Rectangular ASTM F88</td>
<td>Rectangular ASTM F88 and backing up with transparent tape</td>
<td>Dumbbell-shape</td>
<td></td>
</tr>
</tbody>
</table>
3. Results and discussion

The completed product are cut and tested. It is found that failure modes of PE sample is elongation, and tearing. Melting range of PE is 102-115°C. The results of heat seal strength shows in figure 4.

4. Discussion of experiment

Heat seal strength in Figure 4 is different because of the following reasons. Sample 1 is a conventional heat seal testing machine and heating temperature range is very wide about 5-10°C but Peeling seal zone of PE sample in Figure 1 is about 1-2°C. The manufacturers rely on ASTM F2029. Therefore Peel seal zone cannot be detected, it bias to Tear seal zone. The failure mode of heat seal strength is elongation, then maximum heat seal strength decreases because sample elongates. Thus, heat seal strength characteristic in the graph is not perfected. Sample 2 is a result from laboratory testing. The surfaces of heating blocks are coated with 0.1mm Teflon fabric which provides high heat resistance. Temperature at the interface of material reduce because heat resistance. The surface of heat jaw is used knurling surface of heat jaw, it produces pinhole. The sharp edge of knurling portion presses into the material. Some portion of heat seal area is not completed because of air pocket. Heat seal strength between Peel seal zone is lower a half from heat seal strength with flat surfaces heating block at the same temperature. [14] Dwell time is 1sec, temperature is insufficient. Sample 3, 4, 5 are results from innovative method. Temperature controllers of upper jaw and lower jaw are separated and adjusted/shifted to be the same response and reference. The maximum heat seal strength of sample 3 is similar sample 2 but the failure mode is elongation. The maximum heat seal strength of sample 4, and 5 are accurate heat seal strength. They increased due to no elongation of material. Temperature traceability is temperature calibration in every step in the heat sealing process. In conventional method, many heat seal stake holders trust in the display of heat sealing machine. In proposed method, we calibrate temperature such as Display of digital controller, and Display of surface of heating block sensor by using Calibrated digital thermometer before testing.

5. Conclusion

In manufacturers, starting heating temperature is based on trial and error method or material specification from manufacturers or reference book. The weak points of conventional standards and operations are such as; Stake holder couldn’t solve heat sealing problems they have even though they used conventional methods because it does not indicate to heating temperature and conventional methods induces cohesive bonding. Stake holder can not utilize Peel range. With conventional methods, it cannot distinguish the difference between adhesion condition and cohesion condition. Conventional methods does not express high-precision measurement of heat seal strength, because it does not consider following 1) Temperature intervals. 2) Thickness of sample. 3) The position of sample on heating block. 4) Seal area of sample. Conventional methods suggest using heat flow control such Teflon etc. Manufacturers should consider slippage of the temperature controller, the temperature difference of surface temperature and temperature controller, and the difference of surface temperature of heating block and melting surface temperature. In addition, peel seal range, and tear seal range can be defined by MTMS rightfully. In this research, the results of the experiments show the heat sealing problems but it can also lead to the analysis of packaging function of heat seal strength.
References


