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APPLICATION OF POLYETHYLENE HEAT SEAL

CHARACTERISTICS TO SOLVE A HEAT SEAL STRENGTH PROBLEM

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APPLICATION OF POLYETHYLENE HEAT SEAL

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By

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ABSTRACT

APPLICATION OF POLYETHYLENE HEAT SEAL

CHARACTERISTICS TO SOLVE A HEAT SEAL STRENGTH PROBLEM

By

Melvin S. Harder

The use of flexible packaging in the food industry is expanding very rapidly. Milk, traditionally packaged in blown polyethylene bottles, is now being packaged in flexible polyethylene pouches. One problem involves forming a heat seal strong enough to endure the hardships of the distribution environment.

In this study, a material characteristics approach was taken to solve a machine/material interface problem. First, the material was researched to determine the optimum values for the variables; temperature, pressure and dwell time, necessary to form the strongest heat seal possible. Next, the form-fill-seal machine adjustments for temperature and dwell time were changed to the optimum heat seal strength values. The resulting heat seals proved to be stronger than the previously formed heat seals.

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INTRODUCTION

The use of flexible packaging in the food industry is expanding very rapidly. Milk, traditionally packaged in blown polyethylene bottles, is now being packaged in flexible polyethylene pouches. The cost savings are substantial. A blown polyethylene bottle costs about fifteen cents plus one cent for the cap. A pouch only costs three cents. With this magnitude of cost savings available, the switch from bottles to pouches has some very appealing economic advantages. Unfortunately, there are some problems with the flexible pouches. One problem involves forming a heat seal strong enough to endure the hardships of the distribution environment. A strong seal is necessary to prevent undesirable leakage, premature spoilage and unsightly appearance. To accomplish all of these objectives, an appropriate application of temperature, pressure and dwell time in forming the heat seal is necessary.

Forming a heat seal in polyethylene is actually a welding of the material or fusion of the material interfaces by melting. The welding is accomplished by a combination of variables; temperature, pressure and dwell time. Each of the variables has an upper and lower limit. Also, there is an optimum value where any deviation from that optimum peak value will result in a weakening of the heat seal being formed. In addition to these limits, the variables are interrelated to each other. A lowering of one variable can be compensated by increasing

another. An increase in temperature, for example, will correspondingly decrease the dwell time necessary to form a heat seal. If too high a temperature is used to decrease the dwell time, the polyethylene being heat sealed will become degraded by the excessive heat.[15]

The heat seals currently being formed by a local company's form-fill-seal machine leak. These "leaking" heat seals are a problem arising from the new application of polyethylene in the food industry. In theory, the heat seal should be stronger than the material being heat sealed. When moderate pressure is applied to the heat seal formed by the local company's form-fill-seal machine, the heat seals fail before the material deforms, and milk leaks out. Leaking pouches are found throughout this company's distribution system. The failure of the heat seal before the material deforms indicates the need for an adjustment to the machinery forming the heat seal.

The methodology of this study was to identify the optimum ranges of the variables; temperature, pressure and dwell time, necessary to form a strong heat seal. Next, the variable adjustments on the form-fill-seal machine were harmonized with the optimum ranges of the variables. A strength test was performed on the heat seals formed under the current variable settings and the new optimum variable settings to determine if the heat seal strength could be improved. The purpose of the study was to increase the strength of the heat seal being formed by making adjustments to the variables; temperature, pressure and dwell time. Any other changes or modifications to the machine or the packaging material were outside the scope of this thesis.

The results of the strength test showed the heat seals formed

under the optimum variable settings were stronger than the current variable setting heat seals.

LITERATURE REVIEW

Heat Sealing of Polyethylene is Actually a Welding of the Material

The heating and pressing of the material together causes the material to be fused or joined by melting. The softening or melting of the material must be done at a gradual rate to allow control of the welding operation. Polyethylene is well suited for welding since it does not have a definite melting point because of the random arrangement of the molecular chains. It softens gradually with an increase in temperature as the weak secondary bonds between the long chains of molecules begin to break down.[2] The gradual softening of polyethylene with an increase in temperature allows the polyethylene to be welded to itself under controlled temperature and pressure conditions.

Polyethylene is welded to itself when it is heat sealed.[14] F. Kohler explains the welding operation of polyethylene very well with the passage:

> The joining of thermoplastic materials by high frequency heat occupies the position of a true welding operation. The applied heat causes the plastics to soften and the surfaces to fuse together. This fusion takes place in a temperature range which depends on the properties of the plastics and is affected by the pressure applied. The achievement of proper welds therefore depends on the attainment of proper temperature at the interface of the material being joined, with a simultaneous application of proper pressure.

In the end of the passage, F. Kohler pointed out there is a proper temperature and a proper pressure to be applied to polyethylene to achieve a proper heat seal.[7] The conditions necessary to achieve the proper heat seal involve specific temperatures and related pressures in the heat seal operation. Since the temperatures and the pressures can be adjusted in the formation of a heat seal, temperatures and pressures are called variables.

The Three Impulse Heat Seal Variables

In an impulse heat sealer, an additional variable, dwell time, is added to the variables of temperature and pressure. In the impulse heat seal operation, the heat seal jaws come together to apply pressure to the material being heat sealed. On one of the jaws is a resistance wire that heats up when electrical current is applied. While the jaws are applying pressure to the material, the resistance wire is heated for a specific length of time and then cooled for a specific length of time. Dwell time is the interval of time the jaws are under pressure and consists of heating dwell time and cooling dwell time.

The three variables; temperature, pressure and dwell time, control the strength of the heat seal being formed.[16] The temperature causes the interfaces between the two surfaces to disappear, the pressure assures intimate contact of the interfaces and the dwell time brings the interfaces to the needed sealing temperature and allows time for cooling with the surfaces held together.[19]

Each of the variables has upper and lower limits. The upper boundary of the temperature range is limited by damage to the material

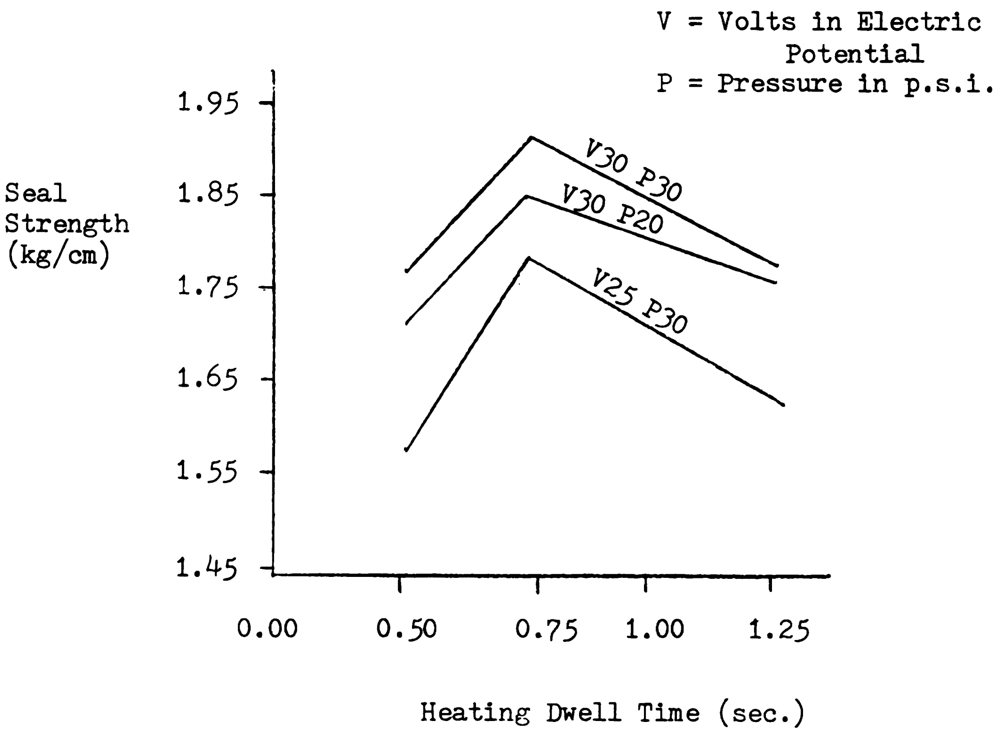
caused by heat degradation. The lower temperature boundary is limited by the amount of heat necessary to melt the interface between the two surfaces to be heat sealed.[19] To form a good heat seal, the temperature must be high enough to melt the interface between the two layers of polyethylene and low enough to prevent heat degradation of the polyethylene.

Pressure is the second variable in the formation of a heat seal and, like temperature, pressure also has upper and lower limits. The upper limit is present because too high a pressure in the heat seal jaws will thin out the polyethylene during formation of the heat seal. A pressure that is very high will extrude the polyethylene from between the heat sealing jaws.[14] The lower limit of the pressure range is the minimum pressure necessary to assure intimate contact between the polyethylene material interfaces. David Pegaz[11] noted the boundaries of pressure when he was studying the bonding rate of polymeric films. He stated in his thesis:

> It can be observed that initially the bond strength values rise with increase in pressure which indicates that some amount of pressure is necessary to overcome a kind of "bonding surface resistance"....with further increase in pressure the bond strength values tend to become lower, or the rate of bond strength growth slows down as if the process of bond formation, diffusion, were laboring against some restrictive force.

The bond strength increases and then decreases as pressure is increased indicating the presence of an optimum range. This supports the previous statement, the pressure must be high enough to assure intimate contact of the interfaces and low enough to prevent a thinning out of the polyethylene at the heat seal area.

The third and last variable, dwell time, also has upper and lower limits. Joseph Miltz observed that heat seal strength passed through a maximum as dwell time increased for all sets of temperature and pressure conditions.[9] Miltz's results can be illustrated on a graph (See Figure 1). The graph shows a family of curves for four mil polyethylene where the temperature and pressure have been held constant while the heated duration of the dwell time was varied from 0.50 to 1.25 seconds. The temperature is expressed in volts of electric potential (V30, V25) and the pressure is expressed in p.s.i. (P30, P20).



SOURCE: Joseph Miltz, "Effect of Structure on Heat Sealing Properties, Seal Strength of LDPEs", Package Development and Systems 10 (March/April 1980): p. 23.

Figure 1. Heat Seal Strength Versus Dwell Time for a Four Mil Polyethylene

The dwell times on the horizontal axis of Figure 1 represent only the time the resistance wire is heated (heating dwell time). The cooling time was held constant at two seconds. In figure 1, dwell times of 0.50 and 1.25 seconds formed a weaker seal for each set of temperature and pressure conditions than 0.75 seconds dwell time (See Table 1).

Table 1. Heat Seal Strengths for Various Temperature and Pressure Conditions

Condition	Temperature Expressed in Voltage	Pressure p.s.i.	Dwell Time 0.50 sec. Strength kg/cm	Dwell Time 0.75 sec. Strength kg/cm	Dwell Time 1.25 sec. Strength kg/cm
1	30	30	1.77	1.92	1.78
2	30	20	1.71	1.85	1.76
3	25	30	1.56	1.78	1.63

SOURCE: From Figure 1, Joseph Miltz, "Effect of Structure on Heat Sealing Properties, Seal Strength of LDPEs", Package Development and Systems 10 (March/April): p. 23.

Miltz's findings showed an optimum dwell time in the formation of a strong heat seal in polyethylene. Insufficient dwell time formed weak heat seals as did too much dwell time.

The Interrelationship of the Three Heat Seal Variables

The three variables; temperature, pressure and dwell time, are interrelated. The largest optimum temperature range in forming a strong heat seal occurs at high temperatures, short dwell times and low pressures. The largest dwell time range occurs at long dwell

times, low temperatures and low pressures (See Table 2).

Table 2. Maximum Range Conditions for Temperature and Dwell Time

Condition	Variable Setting		
Largest Temperature Range	High Temperatures	Short Dwell Times	Low Pressures
Largest Dwell Time Range	Low Temparatures	Long Dwell Times	Low Pressures

SOURCE: R. M. Knight, E. E. Froste and W. U. Funk, "Polyethylene Heat-Seal Factors", Modern Packaging 31 (April 1958): p. 156.

From Table 2, a direct relationship between dwell time and temperature can be seen. An increase in temperature will shorten the dwell time necessary to form a strong heat seal. Similarly, an increase in the dwell time will lower the temperature necessary to form a strong heat seal.

The dwell time required at a given temperature or the temperature required at a given dwell time can be reduced by increasing the pressure.[6] This means an increase in pressure can be used to reduce the temperature and dwell time necessary to form a strong heat seal when the pressure used is within the optimum range. The interrelationship of the three variables is very important and directly relates to heat seal strength.

Summation of the Various Literature Search Concerns

Heat sealing of polyethylene is actually a welding of the

material. The material is fused together by melting. The welding is accomplished by a combination of three variables; temperature, pressure and dwell time.

The variables; temperature, pressure and dwell time, each have upper and lower limits. Too high a temperature will degrade the material and too low a temperature will not melt the interfaces of the material. Enough pressure is needed to assure intimate contact of the material interfaces but too much pressure will thin out the polyethylene in the heat seal area and cause the polyethylene to extrude out of the heat seal jaws. Dwell time has an optimum duration which can be seen from Figure 1. Any increase or decrease in the heating dwell time from the optimum duration will correspondingly decrease the heat seal strength.

In addition to having limits, the three variables are also interrelated. A change in one variable can be compensated by a change in another to form a heat seal. A low temperature can be compensated by a longer dwell time and a short dwell time can be compensated by a higher temperature. An increase in pressure will decrease both the temperature and dwell time necessary to form a heat seal.

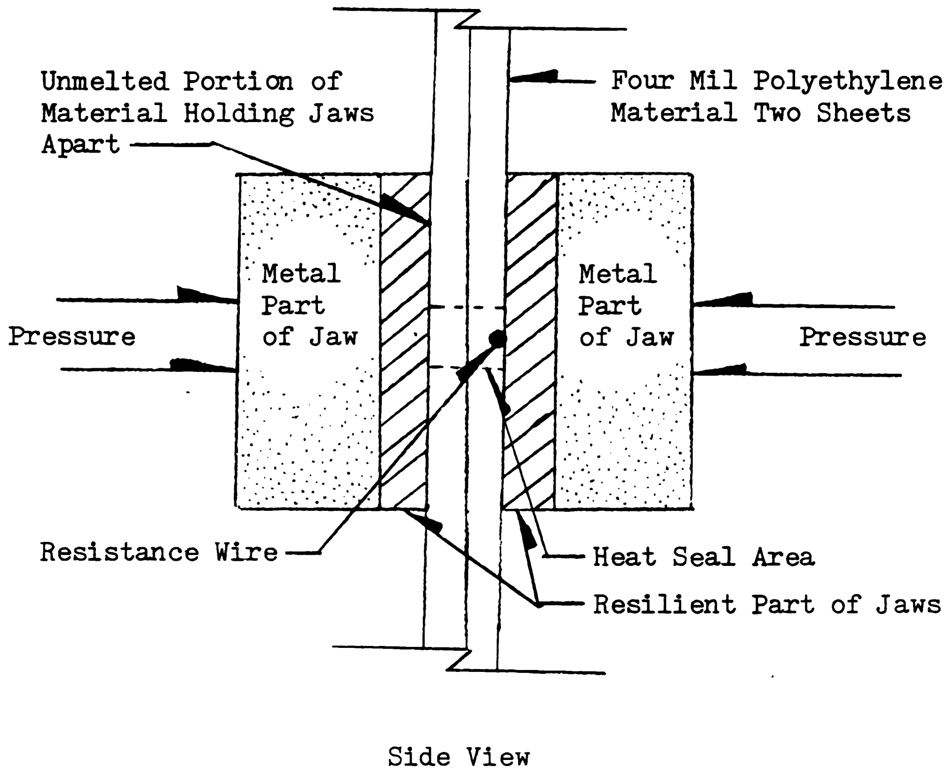
STATEMENT OF THE PROBLEM

Description of an Impulse Heat Sealer

A heat sealing machine brings the thermoplastic material together and, with an application of heat, pressure and dwell time to the interfaces, a weld is formed, sealing the material together. In the impulse heat seal operation, a set of jaws is used to apply pressure to the material interfaces being heat sealed. Inside both of the jaws is a resilient surface to hold the material interfaces in place. On the surface of one of the resilient pads is the resistance wire. While the pressure is being applied by the jaws to the material, electric current is passed through the resistance wire causing the wire to heat up. The amount of current passed through the wire regulates the temperature or amount of heat the material interfaces receive. After the appropriate heating dwell time has passed to raise the material interfaces to welding temperature, the resistance wire is cooled, the jaws open up and release the material, leaving a welded seam between the two interfaces of the polyethylene.

The impulse heat sealer is designed for continuous sealing of unsupported thermoplastic material.[19] During the full pressure jaw closure time of the heat seal operation, the jaws are held apart by the unmelted portion of the material. When the material around the resistance wire is melted, the unmelted material holding the jaws apart prevents the pressure from thinning out the seal area (See

Figure 2). The lower unmelted portion of the film in the jaws also supports the end of the pouch while the resistance wire welds the interfaces together. With these techniques, the impulse heat sealer has the ability to form seals for unsupported thermoplastic materials.



SOURCE: Quality Dairy Form-Fill-Seal Machine, Manufacturer - Societe Prepac, 62 Rue Pastur, Villejuif - 94 - France.

Figure 2. Impulse Heat Sealer

Quality Dairy's Form-Fill-Seal Machine

Quality Dairy Company of Lansing, Michigan elected to switch their packaging of milk from blown polyethylene bottles to flexible polyethylene pouches. The form-fill-seal machine promised to increase productivity, reduce working space, improve packaging efficiency and reduce overall packaging costs.

The machine uses four mil, low density polyethylene film dispensed from a roll located on the back side of the machine. The film travels, from the roll, over the top of the machine where it is folded lengthwise and a vertical heat seal is applied to the loose ends forming a tube. The tube of polyethylene travels down the front of the machine where it is filled with milk. At the bottom of the machine, the polyethylene tube, encasing the milk, is pinched together at ten inch intervals, horizontally heat sealed and cut off. The mechanism that performs the heat sealing and cutting off of the material is called a heat seal cut off bar. The heat seal cut off bar seals the top of the bottom pouch and the bottom of the top pouch while simultaneously separating the two pouches (See Figure 3).

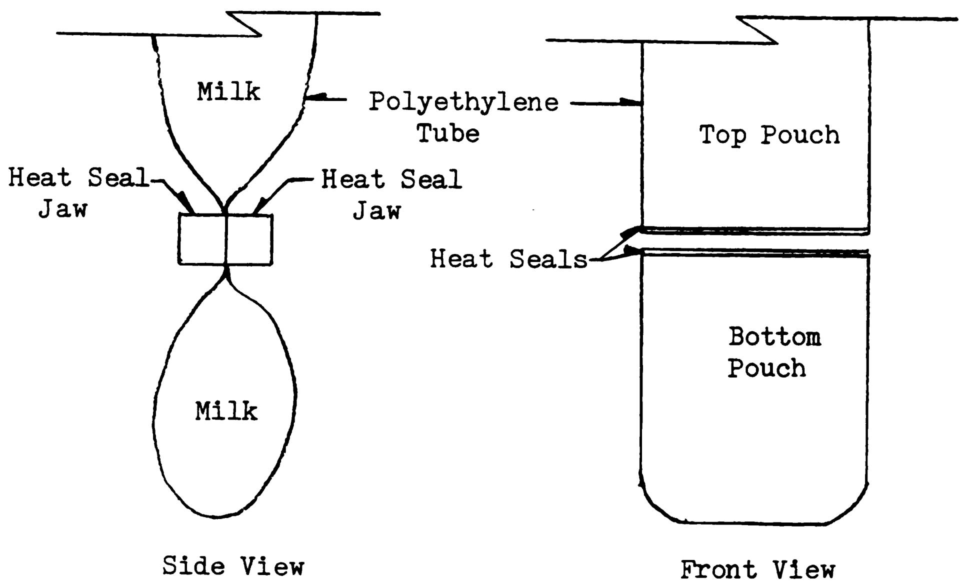


Figure 3. Quality Dairy's Form-Fill-Seal Machine Heat Seal Cut Off Bar

Quality Dairy's form-fill-seal machine can be adjusted for all three heat seal variables; temperature, pressure and dwell time, on the horizontal heat cut off bar. The temperature is adjusted by a large dial located on the front of the machine which is calibrated from 0 - 100. The dial controls the percentage of current entering a transformer. The transformer steps down the source voltage from 220 to 24 volts and passes the current through the resistance wire in the heat seal jaw. For example, if the dial is set at 80%, this means 80% of 220 (176) volts is stepped down to a corresponding 80% of 24 (19) volts and passed through the resistance wire. The temperature control is the easiest to adjust of the three variables and it is changed frequently by the operator.

The pressure is controlled by a 3/16 inch thick rubber strip squeezed between the heat seal jaws of the machine. Standard practice has been to compress the rubber strip to 1/8 inch clearence between the jaws of the heat sealer. The amount of pressure applied to the heat seal depends on the force required to crush the rubber strip. The strip was compressed on a compression tester and it was found that 825 pounds was required to crush the rubber strip to a factory recommended thickness of 1/8 inch. The 825 pound force on the rubber strip equates to 137.5 p.s.i. (See Equation 1).

$$\frac{\text{825 lbs. Force}}{\text{6 inches}^2\text{ Area of Rubber Strip}} = 137.5 \text{ p.s.i.} \tag{1}$$

The pressure adjustment has a locking nut capable of compressing the rubber strip 0.02 inches per half-turn. The rubber strip has a linear relation of compression versus force exerted equal to 825

pounds per 1/16 inch. With a surface area of approximately six square inches on the rubber strip, each half-turn on the locking nut would exert a force of 44 p.s.i. (See Equation 2).

$$\frac{(0.02 \text{ inches})(825 \text{ lbs./ } 1/16 \text{ inch})}{6 \text{ inches}^2 \text{ Area of Rubber Strip}} = 44 \text{ lbs./inch}^2 \text{ (p.s.i.)} \qquad (2)$$

The force of 44 p.s.i. is the minimum pressure the form-fill-seal machine can exert on the material being heat sealed. The factory recommended pressure is 137.5 p.s.i..

The dwell time is controlled by a cam mounted on a shaft. The cam shaft rotates one revolution per heat seal formed and the cam shaft controls jaw closure, dwell time and jaw opening. While rotating, the dwell time cam pushes in a button completing the resistance wire electrical circuit resulting in a flow of current through the resistance wire in the heat seal jaw (See Figure 4).

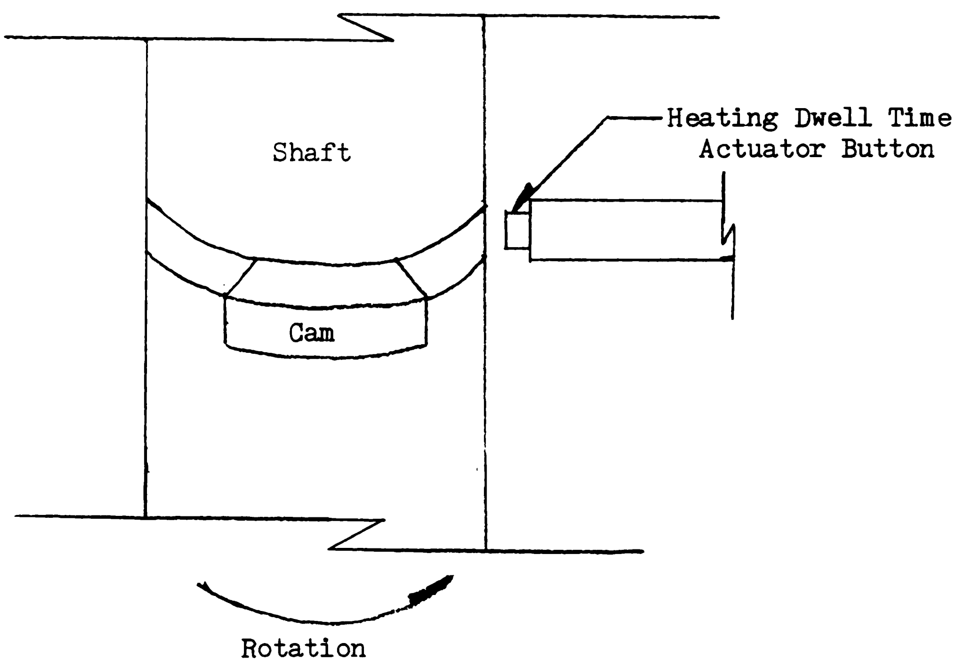


Figure 4. Timing Cam Shaft of the Horizontal Heat Sealer

The dwell time is limited by the full pressure jaw closure time. The heating dwell time is only effective when the material is being squeezed between the heat seal jaws at full pressure. The form-fill-seal machine forms thirty-three seals per minute which equates to 1.8 seconds per revolution of the timing cam shaft. The sequence starts at the 0° mark on the shaft, 110° marks full pressure jaw closure and 280° marks full pressure just before jaw opening. The jaws are at full pressure jaw closure for 170° of the shaft rotation ($280^{\circ} - 110^{\circ} = 170^{\circ}$). The 170° portion of the shaft at 1.8 seconds per revolution equates to 0.85 seconds full pressure jaw closure time (See Equation 3).

$$\frac{(1.8 \text{ sec.})\ (170^{\circ})}{(360^{\circ})} = 0.85 \text{ seconds Full Pressure Jaw Closure Time} \qquad (3)$$

Since the full pressure jaw closure time is 0.85 seconds, the heating dwell time can be adjusted from 0 to 0.85 seconds.

Cooling time normally associated with an impulse heat sealer for this kind of application is unnecessary because the heat seal jaws are pinching off a column of 36°F milk encased in polyethylene. The cold temperature of the milk absorbs the heat of the molten polyethylene almost instantly as the seal is being formed. A summary of the adjustment ranges for temperature, pressure and the heating dwell time is in Table 3.

Table 3. Summary of the Horizontal Heat Seal Variable Adjustment Ranges

	Variable		
	Temperature % Current	Pressure p.s.i.	Heating Dwell Time seconds
Range	0 - 100	44 - 137.5	0.0 - 0.85

The Problem

Five percent of the seals formed by Quality Dairy's form-fill-seal machine are defective. The "leaking" heat seals are a problem arising from the new application of polyethylene in the food industry. A good heat seal is needed to prevent undesirable leakage, premature spoilage, and unsightly appearance. To achieve all these objectives, an appropriate combination of temperature, pressure and dwell time in forming the heat seal is necessary.

The cost of the heat seal leaker problem can be calculated.

14,000	Pouches of Milk Formed per Day
3	Days per Week Operation
42,000	Pouches Formed per Week
52	Weeks per Year
2,184,000	Pouches Formed per Year
5%	Leakers (Conservative Estimate)
109,200	Pouches of Milk Lost Due to Leakers
64¢	Cost of Milk and Package (Estimation)
$69,888	Direct Loss Attributable to the Heat Seal Problem

This simple calculation does not take into account the loss of future sales due to poor performance of the milk pouches used by the customer (i.e. A pouch of milk that leaks in a customers car while he/she is traveling from the store to home).

The temperature adjustment mechanism on the form-fill-seal machine is easy to reach by the machine operator and can be changed while the machine is running. The other two variable adjustment mechanisms are not accessible while the machine is running and are not calibrated. The dwell time variable mechanism is particularly difficult to adjust because any change would require welding additional pieces of metal to the timing cam. With these conditions present, less than optimum settings of the heat seal variables could easily occur resulting in the formation of weak heat seals. In this study the difficult to adjust variable, dwell time, was changed to strengthen the heat seals being formed.

Limits of the Study

The purpose of the study is to increase the strength of the heat seal being formed by Quality Dairy's form-fill-seal machine by making adjustments to the variables; temperature, pressure and dwell time. The study will not consider variations in the pressure over the length of the heat seal, variations in the power supply, changes in the resin composition (density, molecular weight, additives etc.), effect of the film treatment for printing, variations in film thickness, changes to the resistance wire or resilient jaw pad, variations in temperature of the jaw cooling water and continuity of the heat seal.

The ultimate objective of the study is to identify the optimum ranges of the variables; temperature, pressure and dwell time, to form a strong heat seal and adjust the form-fill-seal machine to conform with the optimum ranges. Any other changes or modifications to the machine or the packaging material will be outside the scope of this thesis.

METHODOLOGY

Basis for Procedure

In Joseph Miltz's article "Effect of Structure on Heat Sealing Properties, Seal Strength of LDPEs",[9] he found the seal strength had an optimum heating dwell time setting for all combinations of temperature and pressure conditions. This relationship is very important to a heat seal machine operator. If the machine is forming weak seals, the machine operator must know which side of the seal strength versus heating dwell time curve peak the heating dwell time is currently set. If the heating dwell time is set on the left side of the curve peak, he should increase the heating dwell time to increase the heat seal strength (See Figure 5).

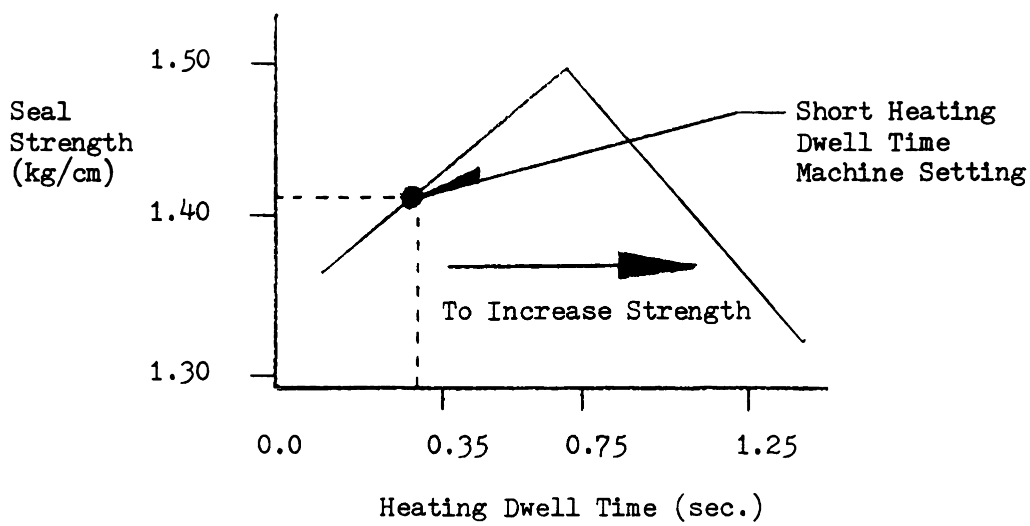


Figure 5. Heat Seal Strength Versus Heating Dwell Time for Four Mil Polyethylene (Short Heating Dwell Time Machine Setting)

Conversely, if the heating dwell time setting is on the right side of the curve peak, the operator should decrease the heating dwell time to increase the seal strength (See Figure 6).

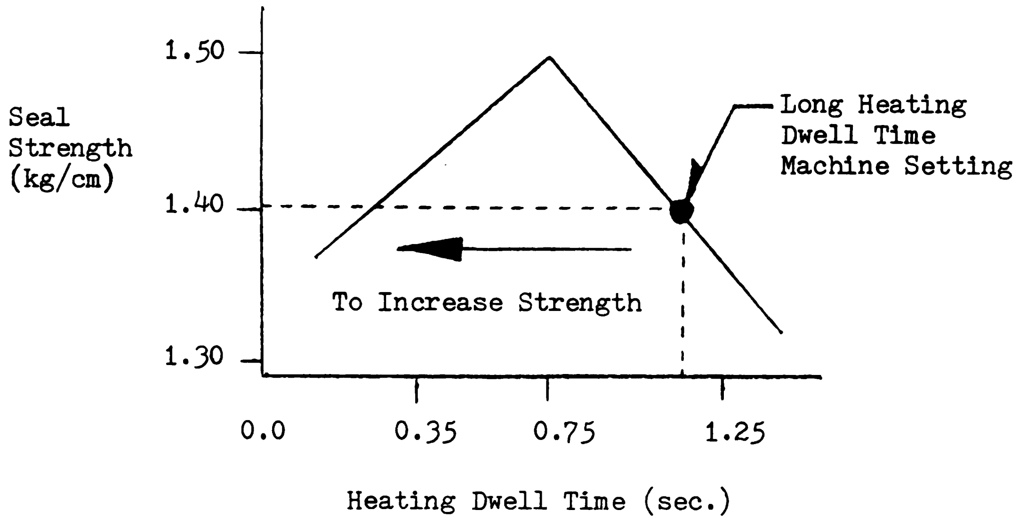


Figure 6. Heat Seal Strength Versus Heating Dwell Time for Four Mil Polyethylene (Long Heating Dwell Time Machine Setting)

The first step in solving the heat seal leaker problem is to identify the current settings of the variables in the horizontal heat seal jaw. In this case the temperature is set at 80%. The amount of pressure applied to the heat seal depends on the force required to crush the rubber strip between the heat seal jaws. From Equation 1 in the preceding section, the current pressure setting is 137.5 p.s.i.. The heating dwell time is controlled by the length of the cam on the timing cam shaft (See Figure 4). The length of the horizontal heat sealer heating dwell time cam is 80°. The 80° length equates to 0.40 seconds heating dwell time (See Eqation 5).

$$\frac{(1.8 \text{ sec. Revolution Time})(80^\circ \text{ Dwell Time Cam Length})}{(360^\circ \text{ Full Revolution})} = 0.40 \text{ sec.} \quad (5)$$

The current settings of temperature, pressure and heating dwell time of the horizontal heat sealer are enumerated in Table 4.

Table 4. Summary of the Variables: Current Settings

	Variables		
	Temperature % Current	Pressure p.s.i.	Heating Dwell Time seconds
Current Settings	80	137.5	0.40

The next step is to identify optimum settings of the variables to form a strong heat seal using four mil polyethylene. The temperature should be set just high enough to melt the interfaces between the two surfaces to be heat sealed. This setting can be easily determined by running pouches through the horizontal heat sealer at different temperature settings and observing the setting at which the melting of the polyethylene begins.

Joseph Miltz observed twenty p.s.i. as being the optimum pressure for heat sealing four mil polyethylene having the characteristics of Quality Dairy's film (See Appendix A). Any pressure above or below twenty p.s.i. will weaken the heat seal being formed.[9] He also found the heating dwell time formed an optimum seal strength at a 0.75 sec. duration. In his experiment, he used a 0.75 sec. heating dwell time coupled with a two second cooling dwell time. In Quality Dairy's application, the two second cooling dwell time is unnecessary because the cold temperature of the milk absorbs the heat from the molten polyethylene almost instantly. With these optimum settings identified and the current settings calculated, a comparison of the differences and a determination of the adjustments necessary to change the variables to the optimum settings can be made (See Table 5).

Table 5. Comparison of Variable Current Settings, Variable Optimum Settings and Variable Adjustment Ranges

	Variables		
	Temperature % Current	Pressure p.s.i.	Heating Dwell Time seconds
Current Setting	80	137.5	0.40
Optimum Setting	---	20	0.75
Adjustment Range	0 - 100	44 - 137.5	0.0 - 0.85

The final step was to make the adjustments necessary to change the current variable settings to coincide as nearly as possible with the optimum variable settings. The temperature will automatically adjust to the optimum setting when the voltage is adjusted to the setting at which the two interface surfaces begin to melt. The pressure setting could not be adjusted to the optimum value because the management of Quality Dairy was reluctant to make any time consuming changes to the machine. For the test conditions, the pressure remained constant at 137.5 p.s.i.. The heating dwell time can be increased from the current setting, 0.40 seconds, to the optimum setting, 0.75 seconds, by increasing the length of the heating dwell time cam from 80° to 150° (See Equation 6).

$$\frac{(0.75 \text{ sec. Optimum Dwell Time})(360^\circ \text{ Full Revolution})}{(1.8 \text{ sec. Revolution Time})} = 150^\circ \text{ Cam Length} \tag{6}$$

Unfortunately, to increase the cam from the current length of 80° to the optimum length of 150° required welding an additional piece of metal to the timing shaft. Again, the management of Quality Dairy was reluctant to make any permanent changes to the machine. In order to increase the heating dwell time without performing any permanent changes to the machine, the heating dwell time actuator button was activated manually during the entire heat seal cycle. Since the dwell time is only effective during the full pressure jaw closure time, this action resulted in a heating dwell time equal to the full pressure jaw closure time or 0.85 seconds. The increased heating dwell time of 0.85 seconds was longer than the optimum dwell time of 0.75 seconds. However, 0.85 seconds is closer to the optimum than the current setting of 0.40 seconds. In the adjusted settings, increasing the heating dwell time from 0.40 seconds to 0.85 seconds correspondingly lowered the temperature necessary to weld the material interfaces from 80% to 42%. Condition I was 80% current and 0.40 seconds heating dwell time. Condition II was 42% current and 0.85 seconds heating dwell time (See Table 6).

Table 6. Comparison of Current Variable Settings (Seal Condition I) to the Adjusted Variable Settings (Seal Condition II)

	Variables		
	Temperature % Current	Pressure p.s.i.	Heating Dwell Time seconds
Current Variable Settings (Sealing Condition I)	80	137.5	0.40
Adjusted Variable Settings (Sealing Condition II). . . .	42	137.5	0.85

Test Used

The method of test selected to determine the strength of the heat seals must be capable of detecting and quatifying the strength difference between the heat seals in the two sealing conditions. In addition, the test results and method must be applicable to other studies and furture works.

A standard test capable of fulfilling the requirements of strength determination and results uniformity was ASTM test D 882-75b.[1] The ASTM test was capable of detecting heat seal strength differences and the method of test was similiar to the one used by Joseph Miltz in his study.[9] The ASTM test was also recommended by the US Army Natick Research and Development Laboratories as the accepted standard test for determining heat seal strength (See Appendix B). For the purposes of this study, ASTM test D 882-75b was used as the test for strength determination and results uniformity.

Test Sample Size Determination

A pilot study was done to determine the sample size of the main study. The pilot study consisted of six seals formed under each condition. A one inch wide and four inch long strip of polyethylene was cut from the heat sealed pouches with the heat seal in the center of the strip (See Appendix C). The test samples were cut from the same place on each pouch (See Figure 7).

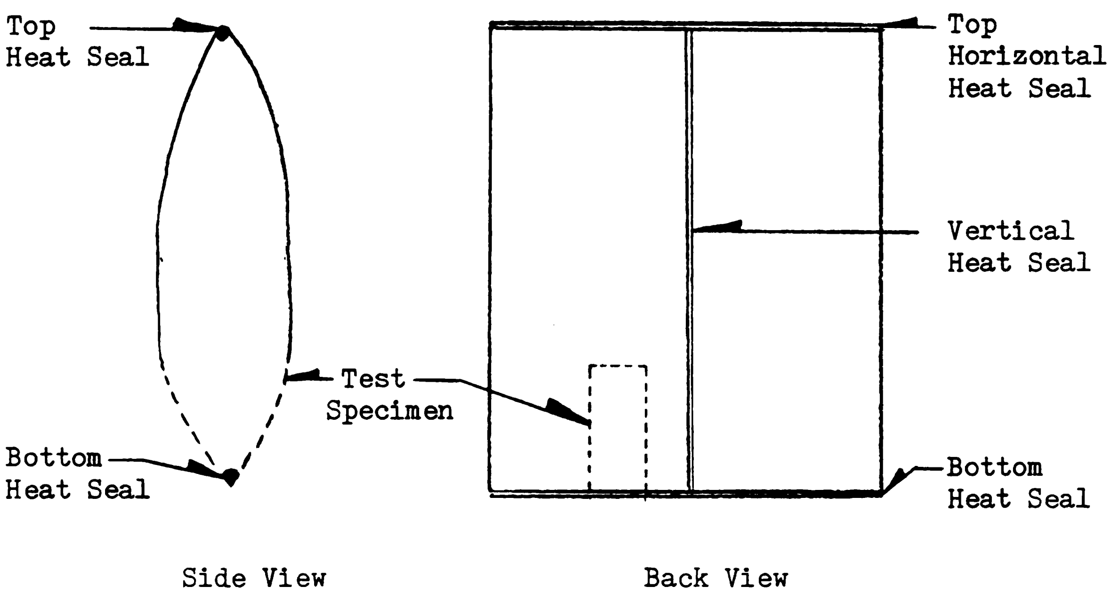


Figure 7. Quality Dairy Half-Gallon Milk Pouch

The test specimens were subjected to a grip separation of ten inches per minute in accordance with ASTM test D 882-75b on the Instron Tensile Tester Machine. This result was recorded as pounds per inch of heat seal length since the specimens were one inch wide. The pilot study temperature variable differed from the main study. In Condition I the pilot study current was set at 55% as compared to 80% in the main study. In Condition II the pilot study current was set at 30% as compared to 42% in the main study. The other two variables, pressure and heating dwell time, were the same for both the pilot and main study.

The results of the pilot study, with six seals under each condition, had a mean difference of 1.1 pounds per inch of heat seal length between the two sealing conditions in favor of Condition II, with a pooled standard deviation of 0.45 (See Appendix D for Results of the Pilot Study). With a 1.1 pound per inch difference between the two conditions and a pooled standard deviation of 0.45, the necessary sample size was determined for the main study. For a Student's t-test at a 99% significance level, a mean difference of 0.5 lbs./inch could be detected with a 0.99 probability (i.e. "power of the test) by using 40 samples under each condition.[4]

During the pilot test sealing operation, a couple of the pouches were subjected to a simple squeeze test where the pouches were hand squeezed until the package ruptured. Condition I seals failed by rupture of the material at the heat seal. In Condition II, the material of the pouch deformed at some point well away from the seal area, leaving the heat seal intact. While this was qualitative only, and was not really a test, it is indicative of different failure modes for the two sealing conditions.

The Test

Forty samples were run off at each condition for the main study. Condition I was the heat seals formed by the variable settings that were currently being used. Condition II was the heat seals formed by adjusting the temperature and heating dwell time (See Table 6). The samples were run off in the middle of the production day at 12:30 P.M..

A section of the material was also collected to perform a "material only" tensile test. The purpose of the "material only" test was to set an upper limit on the heat seal strength to be achieved. A heat seal, when formed properly, should be stronger than the material being sealed together.[16]

RESULTS/DISCUSSION/CONCLUSION

The Results

The heat seal strength test was conducted in accordance with the procedures in ASTM test D 882-75b. The test was done on the material only, Condition I seals, and Condition II seals (See Table 7 for Summary of Averaged Test Values)(See Appendix E for Results of the Material Only Test, See Appendix F for the Results of Condition I Seal Test and Condition II Seal Test).

Table 7. Result Averages of ASTM Test D 882-75b

	Breaking Factor lbs./inch (1)	% Elongation at Break (2)	Tensile Strength p.s.i. (3)
Material Without Heat Seal	7.91	866.3	2610
Heat Seal Condition I	3.65	343.5	1200
Heat Seal Condition II	4.58	591.4	1490
Difference Between Condition I and Condition II	0.93	247.9	290
% Change	25	72	24

The mean results and standard errors of means from 40 seals were 3.65 ± 0.30 lbs./inch for Condition I seals and 4.58 ± 0.30 lbs./ inch for Condition II seals. A pooled standard deviation was used to calculate standard errors because the variances within the two groups were not significantly different (0.0333 and 0.0391). A Student's t - Test of mean difference provided a test statistic of 21.63 (See Appendix G) versus a critical value of 3.421 at the 99.9% level of confidence. This means that the observed difference was significant and Condition II seals were stronger than Condition I seals (In fact the minimum value for any seal under Condition II was as high as the maximum value for any seal under Condition I).

Discussion

Adjusting the variable settings for Condition II seals resulted in a 25% increase in strength as compared to Condition I seals. All of the seals were well below the material strength indicating the improved seals in Condition II were still not being properly formed. The increase in seal strength exhibited by Condition II seals supports Joseph Miltz's findings about optimum variable settings to form a strong heat seal. Miltz discovered: "At all voltage/pressure combinations used the seal strength passed through a maximum as sealing time was increased." When temperature and pressure were held constant and the heating dwell time was varied from 0.50 to 1.25 seconds, the strength of the heat seal passed through a maximum strength value at 0.75 seconds for a four mil polyethylene film.

It was also observed that the average elongation at break was much less for Condition I seals than for Condition II seals, and the standard deviation of the elongation at break was much higher (145.22% versus 33.59%) for Condition I seals than for Condition II seals. In addition, the standard deviation was a much higher percentage of the average elongation at break for Condition I (42%) than for Condition II (6%) (See Appendix F).

The seal lines for Condition I seals and Condition II seals were examined to determine any physical evidence of differences. Under a 48X microscope the seal lines formed under Condition I showed a number of microscopic holes or uneven concentrations of material between the two layers of polyethylene being heat sealed. Condition II seal lines showed a lesser number of microscopic holes or uneven concentrations of material (See Figure 8).

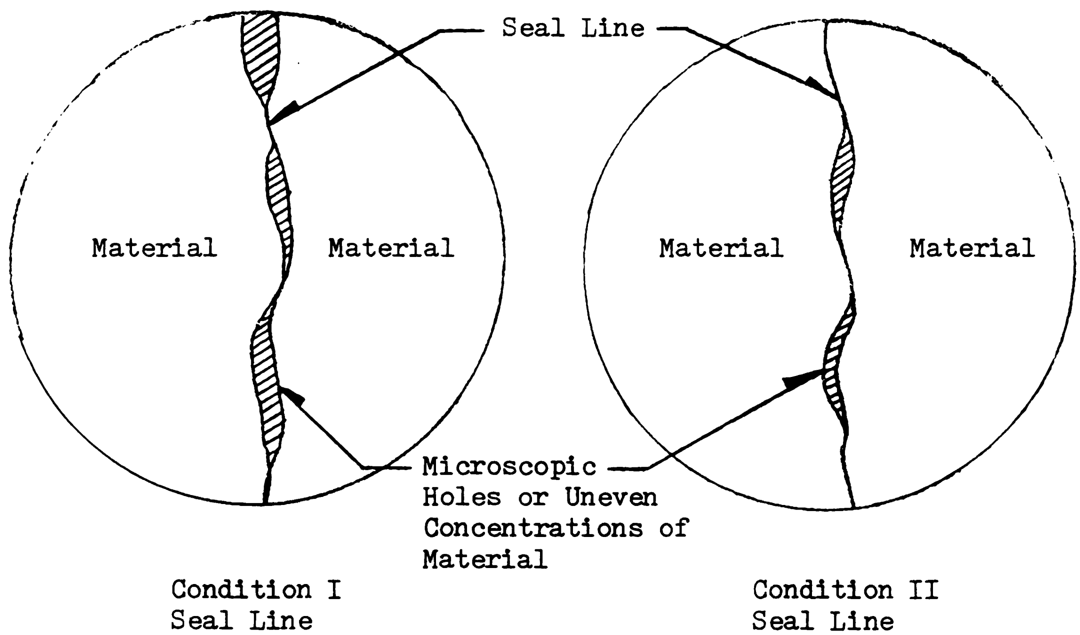


Figure 8. Seal Lines Formed Under Condition I and Condition II (Drawings of Observations Made at 48X Magnification)

The increased duration of the heating dwell time in Condition II seals could have allowed more time for the molten polyethylene to flow together (molecular netting of molecules) thus, reducing the number and size of microscopic holes or uneven concentrations of material in the seal lines. The reduction in number and size of the microscopic holes or uneven concentrations of material could have increased the area of contact between the two material interfaces resulting in the formation of a stronger heat seal.

The difference seen in the standard deviations of elongation at break between Condition I seals and Condition II seals tends to support this theory. The high standard deviation value for elongation at break in Condition I seals could be caused by the random number and size of the microscopic holes or uneven concentrations of material in the seal lines. The reduction of the size and number of microscopic or uneven concentrations of material in Condition II seals could account for the lower standard deviation and increase in seal strength. The increased area of contact between the two material interfaces in Condition II could have formed a more uniform and stronger seal.

Conclusion

In this study, the known properties of a material were applied to a packaging process to achieve a desired result. The known properties of the material determined the optimum settings for temperature, pressure and dwell time to form a strong heat seal. Two of the optimum settings were applied to a form-fill-seal machine and the heat seals formed under the two optimum settings were tested. The test results supported Joseph Miltz's findings about the optimum settings of the variables. Only two of the three variables were changed but the changed variables formed a 25% stronger heat seal than the previously used variable settings. The increase in strength seen in Condition II seals could have been caused by the longer heating dwell time. The longer heating dwell time may have allowed the molten polyethylene to flow together more thoroughly thus reducing the number and size of the microscopic holes or uneven concentrations of material in the heat seal.

Areas for Further Study

A properly formed heat seal should be stronger than the material itself.[17] In this study, the formed heat seals never reached the strength of the material (See Table 7). This fact indicates the need for further adjustments of the variables and further investigation of the form-fill-seal machine. The pressure variable was not adjusted and the presently used setting of 137.5 p.s.i. was well over the optimum value of 20 p.s.i. prescribed by Joseph Miltz.[9] The high pressure setting could be part of the cause of the less than optimum strength of the heat seals being formed.[18] In another study the pressure should be adjusted along with temperature and dwell time to see if the seal strength can be increased.

Unfortunately, the ASTM test used does not simulate the distribution environment. The specified grip separation speed of ten inches per minute on the Instron Tensile Tester was not fast enough to simulate the rate of stress the heat seals will have to endure when subjected to shipment shock and vibration. A further study should be conducted to design a test method capable of simulating the distribution environment and test the heat seals formed under various conditions. This type of study could directly relate heat seal formation to performance.[5]

APPENDICES

APPENDIX A

LETTER FROM DUPONT CANADA INC.

KINGSTON, ONTARIO

cc: D. Ball - CTC

DU PONT CANADA INC.

Research Centre
Research Division
P.O. Box 5000
Kingston, Ontario
K7L 5A5

Tel. 613-544-6400

1981 January 30

Mr. Melvin S. Harder
435 M.A.C.
East Lansing, Michigan. 48823
U.S.A.

Dear Sir:

The following information is in response to your inquiry of 1981-1-16 to Mr. D. Ball regarding our polyethylene liquid packaging film:

Density: 0.919 gm/cm^3
Melt Flow Index: 0.75gm/10min. @ 190°C
Ultimate Tensile Strength: 450kg/cm^2
Mn 30,000 ± 5,000
Mw 120,000 ± 5,000
Mw/Mn ∿4.0
Newtonian Viscosity @ 190°C 250,000 poise

I trust that the above information will be of assistance to your study.

Yours very truly,

DU PONT CANADA INC.

A. N. Mollison

A.N. Mollison

APPENDIX B

LETTER FROM THE US ARMY NATICK

RESEARCH AND DEVELOPMENT LABORATORIES

NATICK, MASSACHUSETTS

DEPARTMENT OF THE ARMY
US ARMY NATICK RESEARCH and DEVELOPMENT LABORATORIES
NATICK, MASSACHUSETTS 01760

REPLY TO
ATTENTION OF:

DRDNA-WP

19 January 1981

Mr. Mel Harder
435 N.A.C.
East Lansing, MI 48823

Dear Mr. Harder:

Reference is made to your phone request of 14 January 1981 regarding ASTM procedures for tensile testing heat seals on 4-mil thick poly bags.

The procedures described in ASTM D882 (inclosed) are applicable. Also inclosed is a sketch showing how the test specimens should be cut and mounted on the tensile tester together with a check list which can be used as a guide in preparing the test specimens, testing, and reporting test results. I believe that this information should help you in your work, but if you should have any further questions, please feel free to call on us again.

Sincerely,

Tedio Ciavarini

TEDIO CIAVARINI
Physical Scientist (Packaging)
Food Packaging and Processing Group
Food Technology Division
Food Engineering Laboratory

2 Incl
As stated

APPENDIX C

DIAGRAM SHOWING HOW THE TEST SPECIMENS WERE CUT FROM THE SAMPLE POUCHES AND DIAGRAM SHOWING HOW THE SPECIMENS WERE POSITIONED IN THE INSTRON TENSILE TESTER

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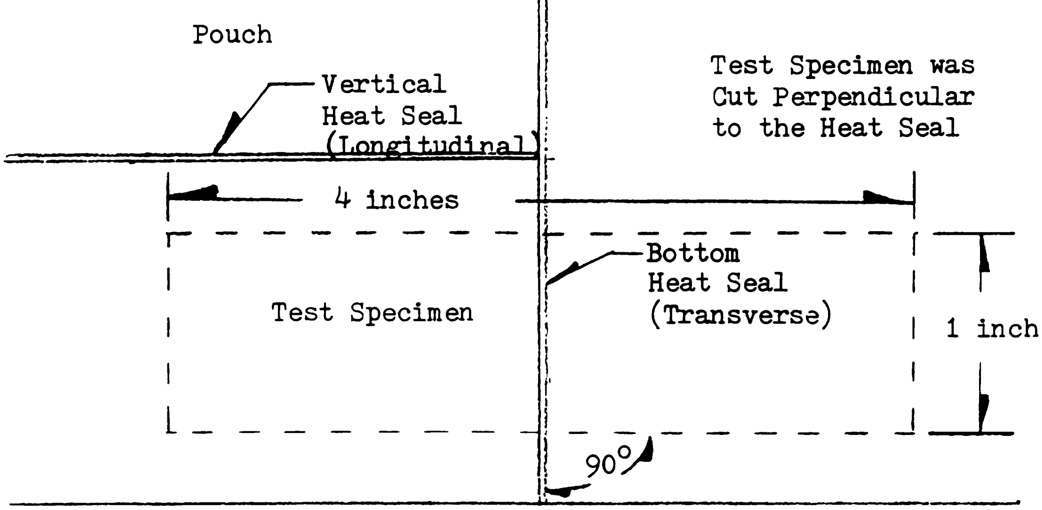
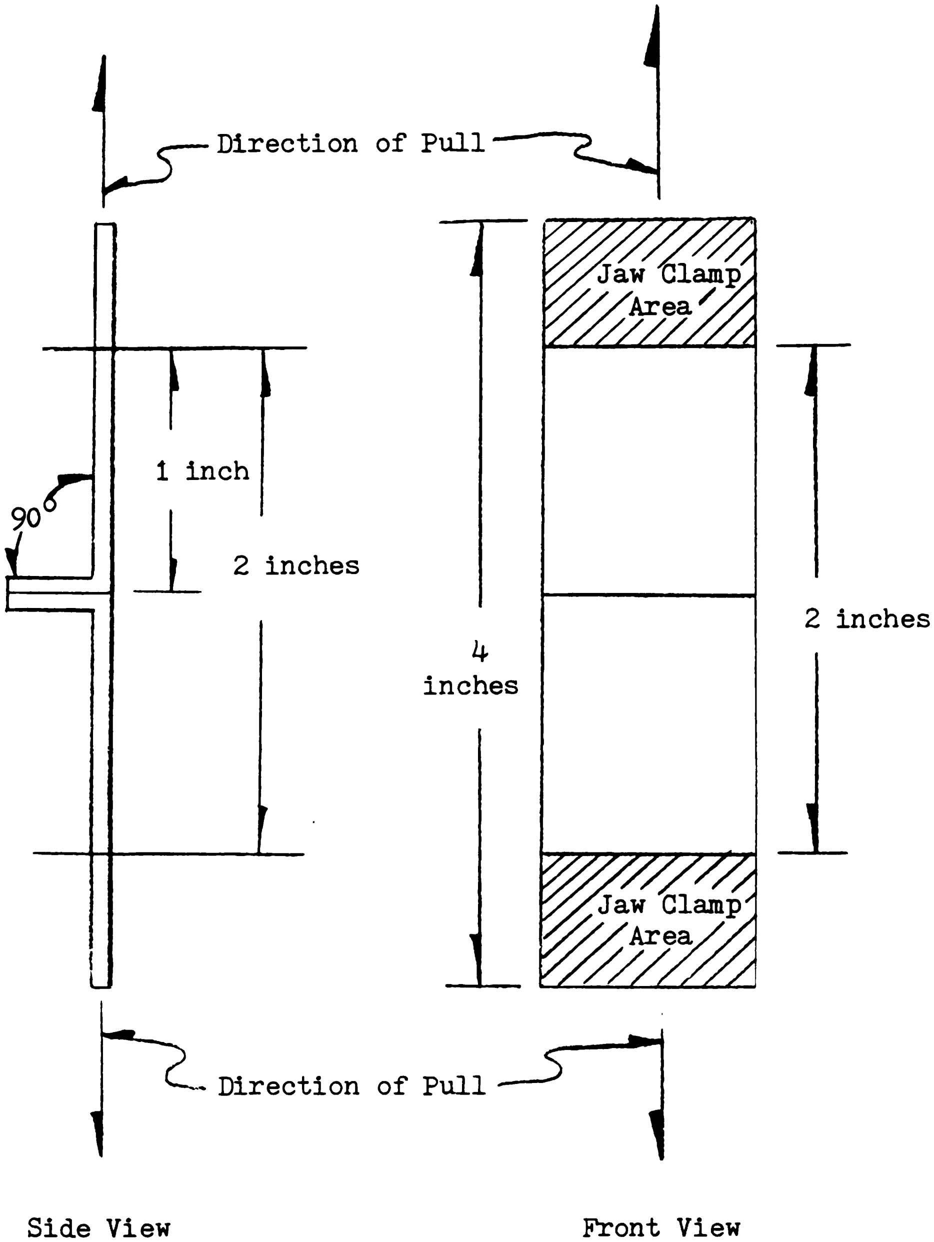
DIAGRAM SHOWING HOW THE TEST SPECIMENS WERE CUT FROM THE SAMPLE POUCHES AND DIAGRAM OF HOW THE SPECIMENS WERE POSITIONED IN THE INSTRON TENSILE TESTER



Pouch Cut Down Both Sides and Laid Down Flat

SOURCE: American Society for Testing Materials. Standard Test Method for Tensile Properties of Thin Plastic Sheeting, D 882-75b.

Figure 9. Diagram Showing How the Test Specimens Were Cut From the Sample Pouches



SOURCE: American Society for Testing Materials. Standard Test Method for Tensile Properties of Thin Plastic Sheeting, D 882-75b.

Figure 10. Diagram Showing How the Specimens Were Positioned in the Instron Tensile Tester

APPENDIX D

PILOT TEST RESULTS

OF HEAT SEAL STRENGTH

APPENDIX D

PILOT TEST RESULTS OF HEAT SEAL STRENGTH

Table 8. Pilot Test Results of Heat Seal Strength

Condition I			Condition II		
Temperature % Current	Pressure p.s.i.	Dwell Time seconds	Temperature % Current	Pressure p.s.i.	Dwell Time seconds
55	137.5	0.40	30	137.5	0.85
Seal	Breaking Factor lbs./inch		Seal	Breaking Factor lbs./inch	
1	4.9		1	6.6	
2	5.45		2	7.4	
3	5.5		3	5.85	
4	5.75		4	6.45	
5	5.3		5	5.9	
6	5.4		6	6.25	
Average	5.38		Average	6.41	
Std Deviation	0.2805		Std Deviation	0.5687	

APPENDIX E

TABLE OF MATERIAL

STRENGTH TEST

ASTM TEST D 882-75b

APPENDIX E

TABLE OF MATERIAL STRENGTH TEST

ASTM TEST D 882-75b

Table 9. Table of Material Strength Test ASTM Test D 882-75b

Seal	Breaking Factor lbs./in.	% Elongation at Break	Tensile Strength p.s.i.	Material Thickness X 10^3
1	7.9	880	2600	3.0
2	7.2	825	2400	3.0
3	7.5	850	2500	3.0
4	7.7	855	2600	3.0
5	8.3	875	2700	3.1
6	7.8	850	2600	3.0
7	7.9	870	2500	3.1
8	8.2	870	2700	3.0
9	8.2	860	2700	3.0
10	8.1	875	2600	3.1
11	8.0	890	2700	3.0
12	8.1	895	2700	3.0
Mean	7.91	866.3	2610	3.03
Std Dev	0.3204	19.44	99.62	0.0452

APPENDIX F

TABLE OF HEAT SEAL STRENGTH TEST RESULTS

AND TABLE OF MATERIAL THICKNESS TESTED

ASTM TEST D 882-75b

APPENDIX F

TABLE OF HEAT SEAL STRENGTH TEST RESULTS

AND TABLE OF MATERIAL THICKNESS TESTED

ASTM TEST D 882-75b

Table 10. Table of Heat Seal Strength Test Results

Condition I				Condition II			
Temperature % Current	Pressure p.s.i.	Dwell Time Seconds		Temperature % Current	Pressure p.s.i.	Dwell Time Seconds	
80	137.5	0.40		42	137.5	0.85	
Seal	Breaking Factor Lbs./in.	% Elongation at Break	Tensile Strength PSI	Seal	Breaking Factor Lbs./in.	% Elongation at Break	Tensile Strength PSI
1	4.0	490	1300	1	4.7	610	1500
2	3.5	90	1100	2	4.8	590	1600
3	3.9	455	1300	3	4.6	600	1500
4	3.9	465	1300	4	4.7	620	1500
5	3.6	385	1200	5	4.0	520	1300
6	3.8	465	1300	6	4.5	575	1500
7	3.8	475	1300	7	4.8	610	1500
8	3.4	125	1100	8	4.4	535	1400
9	3.6	490	1200	9	4.7	615	1600
10	3.8	500	1300	*10	5.3	675	1700
11	3.5	395	1200	11	4.6	580	1500
12	3.7	480	1200	12	4.5	615	1500
13	3.8	480	1300	13	4.8	690	1500
14	3.5	375	1100	14	4.6	570	1500
15	3.4	380	1100	15	4.5	580	1500
16	3.5	420	1100	16	4.7	615	1500
17	3.6	115	1200	17	4.2	565	1400
18	3.4	425	1100	18	4.5	575	1500
19	3.7	470	1300	19	4.7	600	1500
20	3.5	105	1100	20	4.6	530	1500
21	3.4	140	1100	21	4.6	605	1500
22	3.7	325	1200	22	4.7	620	1600
23	3.4	115	1200	23	4.5	575	1500
24	3.4	125	1100	24	4.7	585	1500
25	3.8	475	1300	25	4.6	605	1500

Table 10 - Continued

Condition I				Condition II			
Seal	Breaking Factor lbs./in.	% Elongation at Break	Tensile Strength p.s.i.	Seal	Breaking Factor lbs./in.	% Elongation at Break	Tensile Strength p.s.i.
26	3.5	320	1200	26	4.5	580	1400
27	3.8	450	1300	27	4.6	590	1500
28	4.0	455	1300	28	4.6	600	1500
29	3.5	80	1100	29	4.4	560	1400
30	3.7	250	1200	30	4.6	605	1500
31	3.8	405	1200	31	4.6	615	1500
32	3.5	285	1100	32	4.4	535	1500
33	3.8	420	1200	33	4.4	570	1500
34	3.9	455	1200	34	4.6	615	1500
35	3.6	310	1100	35	4.5	560	1500
36	3.7	415	1200	36	4.4	565	1400
37	3.9	470	1300	37	4.5	590	1400
38	3.5	110	1200	38	4.5	600	1500
39	3.5	155	1200	39	4.5	595	1500
40	3.6	395	1200	40	4.8	615	1500
Mean	3.65	343.5	1200	Mean	4.58	591.4	1490
Std Dev	0.1826	145.22	74.45	Std Dev	0.1977	33.59	65.58
% of Mean	5	42	6		4	6	4

* A suspiciously large value for seal 10 under Condition II (5.3) was determined to be a statistical "outlier" (probability greater than 0.99 that it did not conform to the distribution of values represented by this test). Without the value of 5.3, the mean for Condition II is reduced from 4.58 to 4.56, not altering the basic conclusions at all.

Table 11. Table of Material Thickness Tested

Condition I		Condition II	
Seal Tested	Material Thickness Inches X 10^{-3}	Seal Tested	Material Thickness Inches X 10^{-3}
1	3.2	1	3.1
2	3.1	2	3.0
3	3.1	3	3.1
4	3.1	4	3.1
5	3.0	5	3.0
6	3.0	6	3.1
7	3.0	7	3.2
8	3.0	8	3.1
9	3.0	9	3.0
10	3.0	10	3.2
11	3.0	11	3.1
12	3.1	12	3.0
13	3.0	13	3.2
14	3.1	14	3.1
15	3.1	15	3.1
16	3.1	16	3.1
17	3.1	17	3.1
18	3.0	18	3.1
19	2.9	19	3.1
20	3.1	20	3.0
21	3.0	21	3.1
22	3.1	22	3.0
23	2.9	23	3.1
24	3.0	24	3.2
25	2.9	25	3.1
26	3.0	26	3.2
27	3.0	27	3.0
28	3.0	28	3.1
29	3.2	29	3.1
30	3.1	30	3.0
31	3.1	31	3.0
32	3.1	32	2.9
33	3.1	33	3.0
34	3.2	34	3.0
35	3.2	35	3.1
36	3.1	36	3.1
37	3.1	37	3.2
38	3.0	38	3.1
39	3.0	39	3.0
40	3.1	40	3.1
Mean	3.06 Std Dev 0.0782	Mean	3.08 Std Dev 0.0723

APPENDIX G

STUDENT'S t - TEST FOR BREAKING FACTOR

MEANS AND % ELONGATION MEANS BETWEEN

CONDITION I SEALS AND CONDITION II SEALS

APPENDIX G

STUDENT'S t - TEST FOR BREAKING FACTOR MEANS BETWEEN CONDITION I SEALS AND CONDITION II SEALS

Condition I	Condition II
Xa = 3.6475 lbs./in.	Xb = 4.5800 lbs./in.
Sa = 0.1826	Sb = 0.1977
Na = 40	Nb = 40

(Two Tailed Test) X = Sample Mean

S = Standard Deviation of Sample Data

N = Sample Size

$$\sigma = \sqrt{\frac{NaSa^2 + NbSb^2}{Na + Nb - 2}}$$

$$\sigma = \sqrt{\frac{(40)(0.1826)^2 + (40)(0.1977)^2}{40 + 40 - 2}} = 0.19272$$

$$t = \frac{Xb - Xa}{\sigma\sqrt{\frac{1}{Nb} + \frac{1}{Na}}} \qquad t = \frac{4.5800 - 3.6475}{0.19272\sqrt{\frac{1}{40} + \frac{1}{40}}} = 21.63899$$

t_c = 3.421 for a 99.9% Confidence Level

$$t > t_c$$

$$21.63 > 3.421$$

$\therefore$ Seals formed under Condition II are stronger than those formed under Condition I.

STUDENT'S t - TEST FOR % ELONGATION

MEANS BETWEEN CONDITION I SEALS AND CONDITION II SEALS

Condition I	Condition II
$Xa = 343.5$	$Xb = 591.4$
$Sa = 145.22$	$Sb = 33.59$
$Na = 40$	$Nb = 40$

(Two Tailed Test) X = Sample Mean

S = Standard Deviation of Sample Data

N = Sample Size

Comparing Two Means with Unequal Variances

$$t = \frac{Xb - Xa}{\sqrt{\frac{Sa^2}{Na} + \frac{Sb^2}{Nb}}} \qquad t = \frac{591.4 - 343.5}{\sqrt{\frac{(343.5)^2}{40} + \frac{(591.4)^2}{40}}} = 10.52$$

Critical Value Calculation

$$g = \frac{Sa^2}{Na} \Big/ \frac{Sb^2}{Nb} \qquad g = \frac{(343.5)^2}{40} \Big/ \frac{(591.4)^2}{40} = 18.695$$

Adjusted Degrees of Freedom

$$= \frac{(1 + g)^2}{\frac{g^2 + 1}{(Na - 1)(Nb - 1)}} = \frac{(19.695)^2}{\frac{(18.695)^2}{39} + \frac{1}{39}} = 43$$

$t_c = 3.532$ for a 99.9% Confidence Level

$$t > t_c$$

$$10.52 > 3.532$$

$\therefore$ % Elongation is Greater for Condition II

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BIBLIOGRAPHY

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