Tetra Pak Research & Development AB
Technical Package Development

Packaging Logistics
Department of Design Sciences

Master Dissertation

Secure the robustness of a package

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Preface

This master dissertation is the product of two students work stretching from March 2003 to September 2003 at Tetra Pak Research & Development AB, Lund. It was accomplished to further understand and develop a cartoon platform system. Assigner was Technical Packaging development who also contributed with knowledge, workspace and necessary equipment.

The work has taught us about working with a development project and all that goes with it. During the journey there have been several persons that has helped us, been interested in our work and supported us. We are especially thankful for all that Marie Bengtsson and Lars Svensson, Tetra Pak, has contributed with. They have always given us full permission and never put any restrictions on our work...Full speed all the time.

Without the moral support from Märit Beckeman, LTH, the work would have been so much harder ...Always a smile.

When working with the final folding machine Per-Erik Fahlen and Göran Olsson, Tetra Pak, help has been invaluable...Safety comes first.

Summary

This master dissertation was made during 2003 at technical package development within Tetra pak R&D AB in co-operation with packaging logistics at Lund institute of technology

Theoretic material was gathered from internal development reports, public patents, external literature and interviews with experts within the field. We performed smaller test experiments and analysed them using the simple comparative experiment method. Using the gathered information a theory to plan the multi factor experiments was set up. These multi factor experiments was performed in the final folding machine and tested with a light test method.

The light test is a measurement method that we further developed. It can be used to discover and locate cracks in the aluminium foil. We have also used the light test together with Optimas 6.51 to compare sizes of cracks.

We found that the biggest cracks appeared in the k-zones and therefore we decided to focus only on improvement of these cracks. The improvements that we have worked with are:

- Different crease patterns and different crease types that are known within Tetra Pak. Our results showed that it was possible to reduce the k-cracks by using an optimised crease pattern but the improvement was quite small. One interesting result we found was that on other packages the common used crease type A not was any improvement compared to the alternative crease type D.

- A small change in the way of folding called the S-fold. The packages that have an S-fold on have nearly no cracks compared to the ordinary folded packages. We have also noticed that the packages become more stabile. This fold was known within Tetra Pak in 1980. However it has been forgotten and has staid unused since. We find this solution very interesting to investigate further especially since it can be used on all Tetra Pak packages (such as Brik, Top and Prisma) with K-cracks problem.

- Pre-heating showed, not as suspected, that heat significantly increased k-cracks. This is opposite from earlier results and we have no good explanation why this happened.

- We have also tested a thicker paper board that probably will be used on packages with larger volumes. The thicker paper board showed no significant bigger cracks but the packages tended to be more unstable because of a thicker TS fold.

Table of content

1 Introduction

- What were the purposes with this master dissertation
- What was Tetra Pak interested in investigating
- What was possible to do
- What was not viable during this dissertation

1.1 Background

Tetra Pak started as one of the first packaging companies in the beginning of 1950s. It is now one of the largest suppliers of packaging systems in the world.

We have worked in a project with a new package. The package [Figure 1.1] have a volume that range from 330ml to 1000ml. Some of the beverages that are to be contained in the package have high demands on good oxygen barrier, other different demands such as light sensitivity. More basic demands are that the package is attractive, stable and cheap to manufacture. To fulfil the requirements on the whole package, each and every part of it must be carefully planned

Our job was to thoroughly look into how the bottom should be created to achieve the requirements set on the package. Today the circular bottom is folded as an octagon [Figure 1.2]. This folding process is very complex and no more detailed studies have yet been done on it.

Figure 1.1 Bottom part of the prototype

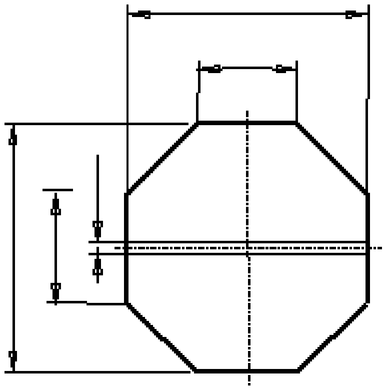

Figure 1.2 The shape of the package's bottom folded octagonal.

1.2 Problem introduction

The complexity with folding the bottom's circular shape is the many sharp folds that occur. These folds involve a high risk of cracks appears in the material. Which is built up by several different material layers; plastic, paper and aluminium [Figure1.3]. The paper layer represent more then 75 % of the entire materials thickness and the aluminium foil will either be stretched or compressed depending on how you fold the material.

Plastic layer (10-15µm)
Paper board (100-600µm)
Plastic layer (10-20µm)
Aluminium foil (6-10µm)
Plastic layer (15-30µm)

Figure 1.3 The different layers in the material[1]

Especially cracks in this layer affect the oxygen barrier of the material in a negative way. If the cracks are large they also affect the aseptic properties.

To reduce these cracks and therefore also improve the oxygen barrier to acceptable levels production parameters must be set in a correct way. This leads to problems, since some of the parameters are very hard and/or expensive to adjust. The quality of the air where the machine operates is a good example of this. Other parameters are

[1] *Package Specifications.* Tetra Pak R&D AB. 030217

not very stable. Noise, such as discontinuities in package material and package position, can make parameters fluctuate in certain intervals. However the comprehensive problem that has to be considered at all times is to fulfil demands of the markets. It must be economic to produce or in the words of Tetra Pak "save more than it costs". This means that the material that has the lowest price and still manage the technical demands will be chosen. Apart from the technical and economical issues the package should also have an attractive, stable and practical design.

The parameters that Tetra Pak found interesting to look at are:

- The quality of the material
    - Thickness of the paperboard
    - Way to apply the plastic layers
- The shape of the bottom and its folding
    - Different folding patterns
- The speed in the folding process
- The shape, pattern and the ratio of the crease
- The moist level of the material
- The force, witch the folding machine use to shape the bottom
- The influence of preheating the creases

It is possible that some of these parameters do not influence the size and amount of cracks and therefore are unnecessary to work with. Other parameters may interact with each other and must be set in a certain relation. Perhaps it is possible to reduce the influence of one parameter by adjusting another one. This may be helpful if it is possible to take away the influence of a parameter that is very hard or expensive to adjust. It is also possible that we find other parameters during the work that we find interesting and decide to investigate them more.

1.3 Objective

The goal was to secure the robustness of the bottom folding process with attention to technical, economical and design factors.

This means:

- That we should improve the folding process so that it gets insensitive to changes in those parameters that are hard to control. In other words, the folding process should be able to work in industrial environments without any disadvantages. A good working process guaranties a package that fulfil the high demands that are put on aseptic packages.
- That we have to decide upon which levels critical parameters are allowed to wary between without disturbing the process.
- That we should find an economically defendable process, in preferably related to material and smaller changes in the machine.

1.4 Focus

We focused on:

- Adjustments and improvements on the folding machine. Does the robustness change when preheating the creases before folding them? If so which values give us the optimum? Are these values adaptable when we are looking at the entire process?
- Improvements of the package. How does the ratio of the creases affect the package robustness? Can we optimise it? How much do small changes in the pattern affect the robustness? Which other parameters have any impact on the robustness? Is it possible to do any small adjustments in the folding pattern?

It is of importance that we through the work also consider and discover which parameters that are hard to control. Can we minimize their influence by adjusting other parameters?

1.5 Boundaries

The boundaries that we in agreement with the supervisors at Tetra Pak set up was:

- Only the bottom part of the package will be tested.
  Our work was only about the bottom folding.
- Only one bottom sizes would be investigated.
  It is necessary to reduce the number of tests.
- Only two types of material will be compared.
  Tetra Pak is only interested in two types of material and the only difference between the two is the thickness of the paperboard. This means that there will be only one type of fibre orientation tested.
- Only materials where the creases are done after the plastic layer is extruded on to the paperboard will be tested.
- The main crease pattern should be the same.
  We are only interested in making small additions or reductions in the crease pattern.
- The speed of the machine is all ready set.
  Requirements from the customer do not allow changes.

2 Methods

- How we generally have gathered information
- How our experiments was planed, carried out and analysed
- A comparison and motives to why we have decided to use these methods
- Which measurement methods that are used within the company to measure cracks

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2.1 Methods generally

To reach the goals and objectives that we have set up it is important that the entire work effort is well structured and fully planed. A test that is poorly planed and/or performed costs a lot of valuable time and most often does not give you accurate results. This means that the test needs to be done one more time or even worse: misleading results may be carried on to the next level and therefore ruin the entire project. In other words:

The result of our work will depend on how well we set up, run and analyse the tests and experiments.

Our work has to be done on a pretty tight time schedule. It will therefore be important that we book equipment and make sure that material are available when we need it. It is also important that we are well aware of how the machines and test equipment work. To keep a structure that is understandable and efficient it is important to use methods for how to set up, run and analyse the different tests. These test methods will be based upon simple comparative experiments and multi factor experiments. To get information and therefore be able to plan these tests as good as possible we will read internal/external literature and have discussions with persons with expertise in the mentioned area.

Each new area that has been tested has started with a thorough literature search. Theoretic material was gathered from internal development reports, public patents and external literature within the field. Using the newfound knowledge interviews with experts in the different areas were done. The goal with the interviews was to find more information but also to confirm if the written information is accurate. We also performed smaller test experiments and analysed them using the simple comparative experiment method. Using the gathered information a theory to plan the multi factor experiments was set up. These multi factor experiments was performed in the final folding machine and tested with a light test method.

2.2 Simple comparative experiment design

To get an understanding of the folding process and see how the different parameters influence the package's robustness in an efficient manner we used the simple comparative experiment design. With this method we can see if a parameter has an impact on the result or not. These trends are really important for the efficiency of the further testing. A non-relevant parameter can be reduced, whilst another parameter might have to be changed remarkably to have an impact.

The tests were mainly be one-factor at a time tests. In some cases were we already from the beginning found the probability for interaction between parameters significant we did two-factor tests (described under multi factor experiment design).

To simplify the experiments as much as possible the tests were run in a test rig that fold the material the way we choose. The machine enabled us to fold single pieces of material in different directions and degrees without changing any advanced settings. This allowed us to do several one-factor at a time tests. Which would help us to see how the different treatments on the material and/or the creases affect the packages robustness. As the theoretical model below describes, it also gave us a better estimation of the standard deviation. By doing a simple and therefore quick test the test size of every treatment could easily be big enough to make the result statistical significant. During the test it was also important to randomise[*] and do correct blockings[**].

2.3 Multi factor experiment design

The trends that the interesting parameters showed us in the single comparative test will now be tested to see two things. Firstly we want to see if the result is accurate in a more complex situation and secondly we want to se if there is any interaction between the parameters. To see this we use a multi factor experiment. This means that we are testing several factors at the same time. These tests will be performed in the final folding machine and be executed on full-scale packages. To find a method that is efficient and fits for our purpose we have studied several authors Box, Hunter and Hunter[2], Bergman[3], Montgomery[4] and Olausson[5]. All of them describe multi factor experiments that originate from the traditional factorial design. One author that differs a little more from the others is Dr Taguchi[6]. He has developed a multi factor method, simply called the Taguchi method. The two ways of doing multi factor experiments are described bellow.

2.3.1 Traditional factorial design

While the environments that the tests are supposed to simulate are very complex with many parameters influencing the result the one-factor-at a time tests do not show a

[*] Randomise: This means that the natural test order is mixed up so that possible process trends wont be result trends for the different parameter settings.
[**] Blocking: If the test series is divided into two or more occasions and for example parameter A is set on a low level the first session and a high level the next. The result might be affected by factors that are not supposed to be studied. To prevent this the natural order is divided so that the different sessions have similar parameter settings.

[2] Box G.E.P, Hunter W.G, Hunter J.S. (1978) *Statistics for Experiments*. John Wiley & Sons, inc
[3] Bergman Bo, Klefsjö Bengt. (1991) *Kvalitet från behov till användning*. Studentlitteratur. Lund
[4] Montgomery Douglas C. (1991) *Design and analysis of experiments*. Third edition. John Wiley & Sons, inc
[5] Olausson, Marie. (1992) *Statistisk försöksplanering Faktorförsök*. Sveriges verkstadsindustrier. Göteborg
[6] Bendell A, Disney J, Pridmore W A. (1989) *Taguchi Methods Applications in world Industry*. IFS Publications. UK

very good picture of the situation. Therefore tests were parameters are changed simultaneously are preferable.

The problem with these kinds of tests is that the number of test runs is growing exponentially. For example if we should test all combinations of two parameters at two levels it will be four combinations. A full two level experiment is often called 2^k were k is the number of parameters that are tested. The value of two subscripted with k gives you the number of parameter combinations. If we should test three parameters at two levels it will be eight combinations and so on. The good thing with these experiments is that they give a very clear understanding of the process and how the parameters are influencing the result both by their own and in interaction with each other. If three parameters as described above are tested then it is possible to detect eight effects from the parameters. These are: one overall average value, three main effects (influence from a single parameter), three two-factor interactions (interactions between two parameters) and one three-factor effect (interactions between all three parameters).

Often is the effect of the three-factor interaction negligible and with some process knowledge some of the two-factor interactions too are negligible. With this in mind it is possible to reduce the size of the test. Reduced experiments are illustrated as 2^{k-p} were p describes how much the experiments are reduced. As the formula describes one experiment that is reduced once will be half the size of a non-reduced experiment. This is a great advantage for saving resources. As mentioned above a problem with reduced tests is that it is not possible to detect all the interaction effects. Depending on the reducing extent there will be a mix up between effects; for example one main effect could be mixed up with a two-factor interaction. Therefore it must be clear which effects that are negligible. Otherwise it will be impossible to get any correct information from the test.

Factors and interactions are assessed to columns. A column is containing all the factor levels. Mostly there are two or three levels described either by numbers or "+" and "-". Each row indicates a combination of factor levels to be run in the experiment.

The columns in the arrays are balanced in a certain manner. For example by looking at column C [Table 2.1] it is easy to see that the first four rows contain factor level 1. All the other columns are balanced so that they contain two factor level one and two factor level two in the four first rows. By designing the arrays in this way the result in the experiment will be as good as possible.

The principle to calculate an effect of a factor is to compare the result of the tests where the factor was at one of the levels with the result where the factor was at another level. For example if the effect factor A [Table 2.2] is to be calculated the average result of rows 1,3,5,7 are compared with the averaged result of rows 2,4,6,8.

Run Number	Factors							Test Result
	A	*B*	*C*	*AB*	*AC*	*BC*	*ABC*	
1	1	1	1	2	2	2	1	*Y1*
2	2	1	1	1	1	2	2	*Y2*
3	1	2	1	1	2	1	2	*Y3*
4	2	2	1	2	1	1	1	*Y4*
5	1	1	2	2	1	1	2	*Y5*
6	2	1	2	1	2	1	1	*Y6*
7	1	2	2	1	1	2	1	*Y7*
8	2	2	2	2	2	2	2	*Y8*

Table 2.1 A 2^3 array, 1 and 2 indicates different factor levels (for example on / off)

If an experiment is reduced, one of the interactions is replaced with a new factor [Table 2.2]

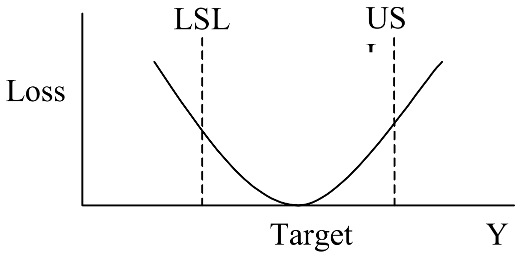
Run Number	Factors							Test Result
	A	*B*	*C*	*D*	*AC*	*BC*	*ABC*	
1	1	1	1	2	2	2	1	*Y1*
2	2	1	1	1	1	2	2	*Y2*
3	1	2	1	1	2	1	2	*Y3*
4	2	2	1	2	1	1	1	*Y4*
5	1	1	2	2	1	1	2	*Y5*
6	2	1	2	1	2	1	1	*Y6*
7	1	2	2	1	1	2	1	*Y7*
8	2	2	2	2	2	2	2	*Y8*

Table 2.2 A 2^{4-1} reduced array, 1 and 2 indicates different factor levels (for example on / off)

2.3.2 Taguchi method

Dr Genichi Taguchi has developed a method that is built upon the traditional factorial design but with some other assumptions that lead to differences in the experimental design. The Taguchi method is actually an entire concept of quality design but we will only describe the theory of experiment building and analyse of the result. It should also be mentioned that the Taguchi method is a commercial concept and therefore the literature that describes it does not always have an objective view. The literature sometimes feels more like commercial text with several examples describing what improvements have been done using the Taguchi Method.

Taguchi's method means that the goal with quality design is to minimise the "loss imparted by the product to the society from the time the product is shipped" [7]. This is important to keep in mind when the Taguchi Method is used. The main goal for his experimental design is not process understanding but cost reduction. The cost can be defined in several ways but a standard definition is the quadratic loss function [Figure 2.1]. The broken lines show the traditional thinking that the result can varies between the Lower Specification Limit, LSL, and the Upper Specification Limit, USL, without disturbing the process and if it is outside there will be a loss. Taguchi thinks that it is reasonable to believe that the loss continually increases as the result deviates farther from the target value. This means that minimising the variation of the result is a central part of the Taguchi theorem.



$$L = k(y - T)^2$$

Figure 2.1 The quadratic loss function. L=loss in dollars; k=cost coefficient; y=value of quality characteristic; T=target value

When the experiment is designed the factors are divided into two parts, controllable factors and noise factors. Controllable factors are those factors that can easily be controlled such as material and cycle time. Noise factors are those nuisance variables, which are difficult, impossible, or expensive to control, for example the surrounding environment, the machines accuracy. The goal with the experiment is to find a way to set the controllable factors so that the mean value gets correct and the noise factors influence on the result gets minimised.

Taguchi use the same kind of arrays as above in his experimental design. There are two big differences between his design and the traditional. First he uses two arrays, inner for the controllable factors and outer for the noise factors and second he reduces the arrays to a very high level [Figure 2.2]. The inner array shows how the controllable factors are set in every run. For every set of controllable factors in the outer array (every row) the noise factors are set at different levels according to the inner array. If the inner array has for example eight rows (eight different set of

[7] Bendell A, Disney J, Pridmore W A. (1989) *Taguchi Methods Applications in world Industry*. IFS Publications. UK

controllable factors) and the outer has four rows (four different set of noise factors) this will lead to 32 runs for the experiment.

The high level of reduction of the experiments is all right if the correct result variable is measured, according to Taguchi. Taguchi means that the effect of interactions that can destroy the result in reduced experiments can be more or less neglected if the result that is measured is chosen so that the variable is energy related. Taguchi is however in some arrays warning for that some columns can be showing interactions instead of main effects. This is showed by linear graphs[8][Figure 2.2].

Run Number	Factors A	B	C	Test Result
1	1	1	1	Y1
2	1	2	2	Y2
3	2	1	2	Y3
4	2	2	1	Y4

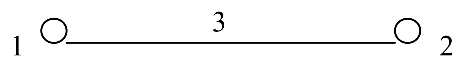


Figure 2.2 Array with linear graph showing that column 3 can show a interaction instead of a main effect, 1 and 2 indicates different factor levels (for example on / off)

To analyse the result a signal to noise ratio is used. There are various signals to noise ratios depending on what type of data that is analysed. Three common signals to noise ratios are Nominal-, Smaller- and Larger-the better. If for example the result should be as close to a nominal value as possible nominal the better are chosen [Equation 2.1].

$$S / N = 20 \cdot Log_{10}\left[\frac{\bar{y}}{\sigma}\right]$$

Equation 2.1 Signal to noise ratio nominal the better, y is the residuals and σ the standard deviation

When the result is analysed the set of controllable factors are set so that the signal to noise ratio are maximized. This means that both mean value and variance are treated in the same variable. This simplifies the calculations when the result is analysed, but it is hard see what really happens in the process.

8 *Robust Design using Taguchi Methods* ASI Quality Systems. (2000)

2.4 Method selection

We have decided to choose the traditional factorial design when our experiments are designed. The main reason for this is that we want to gain good knowledge about the process. First when we have the knowledge and understanding we can start to make improvements. In this case we find that the traditional experimental design gives us a better understanding for the process while the Taguchi method focuses more on just improvements without any deeper understanding
Other argument that motivates our choice is Montgomery's[9] criticism against Taguchi. The main arguments are listed below:

- The assumption that designing the experiment correct can eliminate the two factor interactions is difficult if the process knowledge is low.
- The design with inner and outer arrays gives very big and ineffective experiments. By using one single array and put the noise factors together with the controllable it is possible to either reduce the size of the experiment or to get more knowledge about interactions of higher order.
- Taguchi claims empirically that the use of signal to noise ratio give the best result when the result is optimised but he has not been able to show any scientific proof for this yet.

2.5 Analyse methods of the results

The result of the different treatments are analysed according to a theoretical model [Equation 2.2].

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$
$$\sum_i \tau_i = 0$$
$$\sum_{ij} \varepsilon_{ij} = 0$$

Equation 2.2 y_{ij}=result in the jth observation taken under treatment i. μ=overall mean or reference mean. τ_i=ith treatment effect. ε_{ij}=random error.

ε_{ij} are assumed to be normally and independently distributed random variables with mean zero and variance σ^2. The variance is assumed constant for all levels of factors. In the experiment we want to check if any treatment differs significant from the overall mean or a reference mean [Equation 2.3].

[9] Montgomery Douglas C. (1991) *Design and analysis of experiments*. Third edition. John Wiley & Sons, inc

$$H_0 : \tau_1 = \tau_2 = ... = 0$$
$$H_1 : \tau_i \neq 0$$

Equation 2.3 Hypothesis test, H_0 is rejected if at least one τ_i differs significant from zero

The experiment should show if it is possible to reject the hypothesis H_0 against the H_1 at a certain significance level. If H_0 is rejected this means that one or more of the treatments have a significant effect on the result. To simplify the text in the rapport significant is defined as a difference that is possible to see at a α-value of five percent. A α-value of five percent means that there is a risk of five percent that we make the conclusion that there is a difference between treatments when the difference actually depends on a random error in the test. When several treatments are tested and they each are considered with a α-value of five percent (individual error) there is a small risk (five percent) that one of the treatments shows a significant difference that actually only depends on random error. If the whole test is considered this means that there is a larger risk than five percent (family error) that one of the treatment should show a significant difference that only depend on random error. To avoid misleading result we also set the family error (if it exists) to five percent, this means though that the individual error sometimes becomes even smaller than five percent this to keep the family error at five percent. A significant difference means though that both individual and family errors are at most five percent.

2.6 Measurement methods at Tetra Pak

To measure the result from either simple comparative tests or from the final folding machine we have different tools. Some of which the project already is using and some we have found in other projects within the company.

2.6.1 Conductivity[10]

The conductivity test is a method used to discover if the inner plastic film is damaged.
How does it work
The principle is the same as for an electrolyte cell.
Equipment and handling
A package filled with sodium chloride solution is placed in a bath containing the same solution. If the inner polyethylene layer is damaged there will be a current flowing through the aluminium layer when the solution is connected to a power source.

[10] *Electrical contact to Aluminium foil*. Tetra Pak R&D AB. 020415

Results
If there is a deflection on the ammeter the circuit is closed. In other words there is connection between the aluminium foil and the solution in the package.
Summary
Positive
This is a quick and cheap method to discover if the inner plastic film is damaged.
Negative
The method does not determine if the aluminium layer is damaged. It only tells you if the plastic layer is continuant or not. Nothing is said about the size of the problem.

2.6.2 Red ink[11]

The red ink method is a technique used to find out if the Aluminium foil is damaged.
How does it work
Red ink is pored into the package and if there is a leak in the inner layers it will be visible.
Equipment and handling
The damaged packages discovered with the conductivity test are filled with red ink. If the packages have a rupture in the aluminium foil the ink will seep out to the paperboard layer.
Results
By carefully splitting the package by the paperboard, leaks and their positions are detected.
Summary
Positive
This is a cheap method to see if and where the aluminium foil is damaged.
Negative
The time effort is pretty high since everything has to be completely dry before the result can be analysed.

2.6.3 K-crack evaluation[12]

The k-crack evaluation analyse is used to measure the size of the cracks in the k-crease.
How does it work
Using a magnifying glass to search and measure cracks in the k-crease.
Equipment and handling
Packages that doesn't have a rupture in the inner plastic layer and therefore aren't detected with the conductivity test are cut open and looked at through a magnifying glass to detect possible cracks in the aluminium foil.
Results
The cracks, that usually occurs in the k-crease (for Tetra Brik Aseptic) are counted and measured.

[11] *Red Ink test*. Tetra Pak R&D AB. 020415
[12] *K.Crease cracks evaluation*. Tetra Pak R&D AB. 020425

Summary
Positive
It is a cheap method to discover the size and location of cracks in the aluminium foil.
Negative
The time effort is pretty high.

2.6.4 Oxtran[13]

Oxtran is used to measure how good the package can withstand oxygen.
How does it work
The amount of oxygen the leaks into a package is measured.
Equipment and handling
The package is carefully filled with nitrogen. Then a computer measures the percentage of oxygen that finds its way into the package (through the aluminium foil).
Results
A computer registers the course of events through out a 24-hour period.
Summary
Positive
The method allows you to put an exact (deviation 0,001cm^3/package/24-hour period) number on the leak.
Negative
This is an expensive method and it doesn't discover where the problems are situated.

2.6.5 Origin Light test[14]

The light test is used to see if the Aluminium foil is damaged.
How does it work
An intensive light is used to shine through the aluminium foil.
Equipment and handling
The package is placed on top of a 400W light bulb in a darkroom. When the light bulb is turned on a digital camera snaps a picture of the critical parts on the package.
Results
A study of the bright parts on the picture reveals if and where there are any cracks in the aluminium foil.
Summary
Positive
This is a quick method that reveals where cracks occur in the aluminium foil.
Negative
The method is fairly new and only a few studies of how good the results are have been done.

[13] Dahlberg Lena. Technician/material analysis. Tetra Pak R&D AB. 030305
[14] Nilsson Christer. Development engineer. Tetra Recart AB. 030304

3 Project plan

- Which parts that our work was divided into
- Our time schedule

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3.1

All in all the work progressed from the beginning of March 2003 until the end of September 2003. Roughly the project was divided into five major phases:

Start up	**3 weeks**
Background, problem introduction, objective, focus and boundaries	
Time schedule	
Method analyse	
Test of packages weaknesses and measurement method	**3 weeks**
Building of equipment	
Folding and analyse of the package today	
Evaluation	
Crease test	**8 weeks**
Literature and interviews	
Simple comparative experiment	
Multi factor experiment	
Evaluation	
Paper thickness and preheating test	**5 weeks**
Literature and interviews	
Simple comparative experiment	
Multi factor experiment	
Evaluation	
Rapport and presentation	**1 week**
Rapport and presentation	

Presentation	**5th of September 2003**
Final rapport to Tetra Pak	**23th of September2003**

4 Evaluation of Tetra Pak measurement methods

- An experiment that was set up to see if it is possible to find cracks in the aluminium layer with the light test.
- If there exists any correlation between the light test and Oxtran

4.1 Goal

This first test is launched to further understand the different analysing tools. Is there any correlation between how much light the aluminium foil can not block out, when tested with our modified light test method, and how much oxygen that trickles through the package? If so: can the light test method be used instead of using a combination of Oxtran, to measure a leakage, and some method to localize the leakage? In other words:

Is it possible to put a numeric value on the leakage using the light test method?

4.2 Procedure

The test will be performed on packages manufactured in the final folding machine. All the packages will be cut open to fit the light test method [Appendix 1]. The packages are then divided into two major groups:

1. Group of bottoms to test folded [Figure 4.1] with both the light test and Oxtran.
2. Group of bottoms to test folded and unfolded with the light test and unfolded with Oxtran.

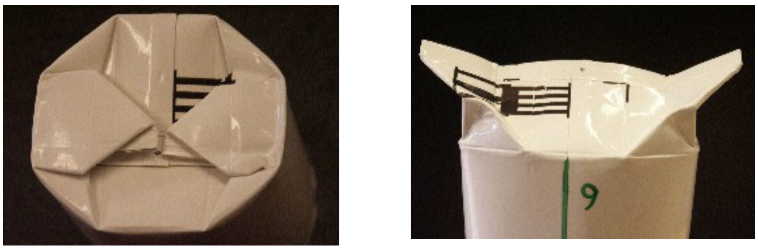


Figure 4.1 Folded and unfolded bottoms illustrated

The reason for unfolding some of the bottoms is to see if this treatment affects the cracks in the aluminium foil.

The entire test series is now analysed with the light test method [Appendix 1]. However due to small resources only three folded and three unfolded were sent of for analyse at the Oxtran laboratory. The given results for the two measurement methods are then compared.

4.3 Result

As covered in the light test description [Appendix 1] the program is set to filter out and detect light at certain brightness at certain wavelength. Each crack that leaks light is obtained and its area and average luminance level are recorded with Optimas 6.51 [Figure 4.2] and further statistical analysed in Minitab 13. The reason for measuring both area and average luminance level is that the small creases can cause a Fresnell[15] bending. This phenomenon bends the light when passing through small holes (diameter about 0,5 µm) that make them look bigger than they really are. By measuring both area and average luminance level this effect will not affect the result[16]. The Oxtran analyse is performed as described in the method chapter.

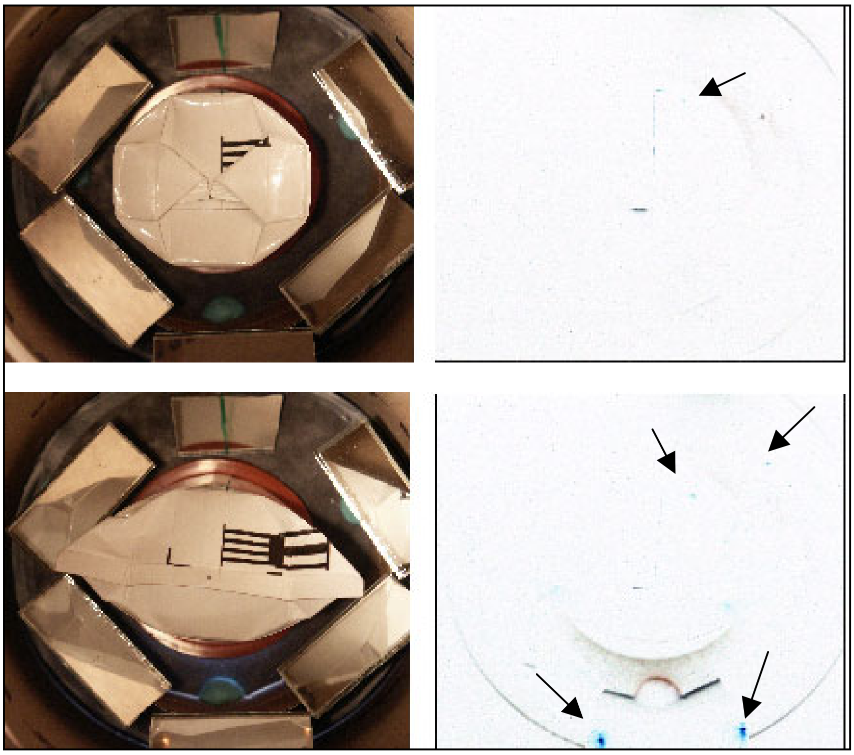


Figure 4.2 TL folded with light, TR negative of folded without light, BL unfolded with light and BR negative of unfolded without light. Points marked with arrows have not blocked the light

The gathered results are presented [Appendix 2] both as tables and graphs. What is notable is that the leakage recorded for the different packages with the light test

[15] Jönsson Göran. (1999) *Våglära och optik*. Second edition Teach support Lund.
[16] Jönsson Göran. University lecturer. Atomic physics LTH Lund. 030409

method well fit a normal distribution curve [Figure 4.4], which states that our assumption, that the residuals are normally distributed, from the method chapter is correct. However it is hard to draw any conclusions from the result registered with Oxtran [Table 4.1].

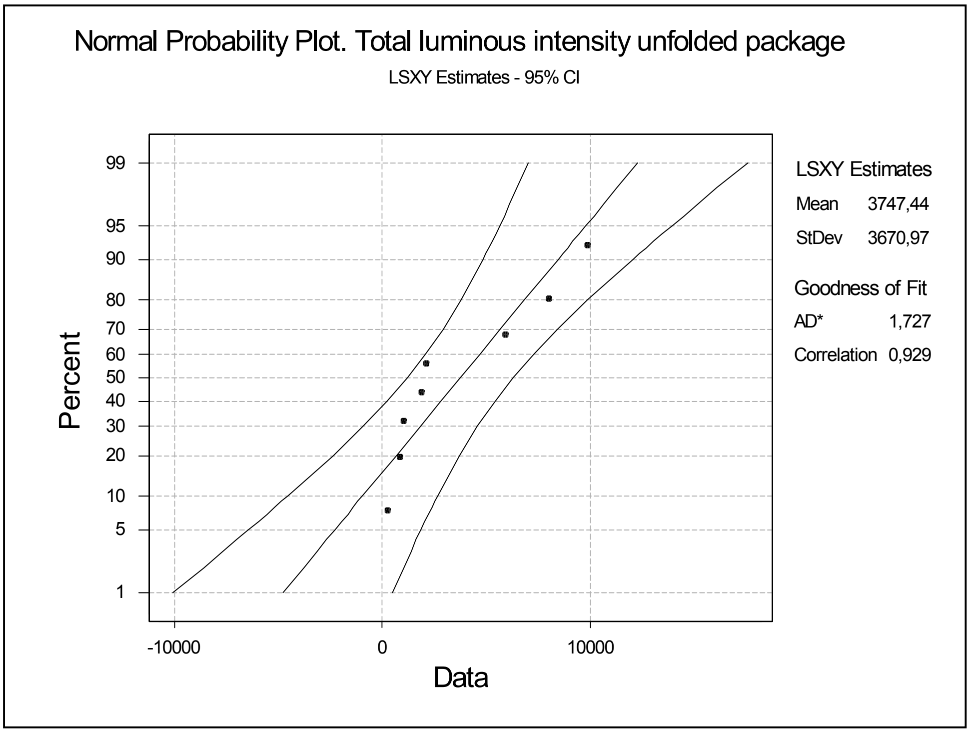


Figure 4.4 Probability plot showing the luminous intensity

Nbr	Oxtran (cc/24h/package)
6	failed
7	failed
11	0,0055
13	0,0068
14	failed
15	0,0055

Table 4.1 Oxtran values

4.4 Conclusion

The goal is to find if there is a correlation between the light test and Oxtran. The results from the light test show clear trends of where the light shines through and hence where weaknesses are. However there is no correlation between the light test and Oxtran. One reason for this could be either that something went wrong during Oxtran or, and more likely, there is other problem areas, regarding oxygen barrier properties, on the package. This is supported by the analyse done by Technical Package Development[17] who on packages from the same series discovered problems with the LS[*]-seal. Since we still believe that there in fact is a correlation we decided to further investigate the light test method.

[17] Bengtsson Marie. Project leader. Tetra Pak R&D AB. 030409

[*] LS: Longitudinal sealing (compare TS: Transversal sealing)

5 Further investigation of the light test

- If it is possible to quantify the result from the light test

5.1 Goal

The purpose with this experiment is to further investigate how well the light test works as a measurement method. The questions we are looking to answer are:

- Are all creases visible on the photos?
- Is it possible to measure the size of a crease?
- Is it possible to reject the null hypotheses that the measured area and total luminous not depends on the size of the holes against the hypotheses that we can separate the holes with the light test?

5.2 Procedure

We use ten material samples in which we make five holes [Table 5.1] of different sizes using a needle. Then the samples are tested in the light test. Every sample is tested twice. One of the samples is tested five times placed in different angels in the light test.

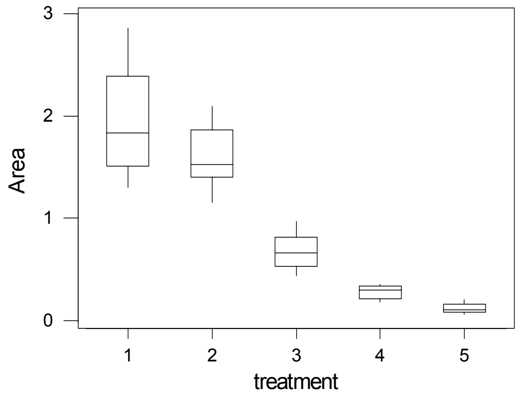
Diameter (mm)	Area (mm^2)
0,31	0,075
0,34	0,091
0,40	0,126
0,63	0,312
0,68	0,363

Table 5.1 Diameter and Area of the holes made in the samples

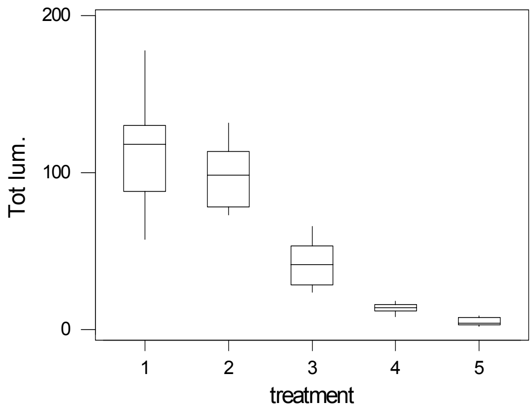
The pictures are analysed in Optimas 6.51 and the result are further statistically analysed in Minitab 13. Both area and total luminous are measured.

5.3 Result

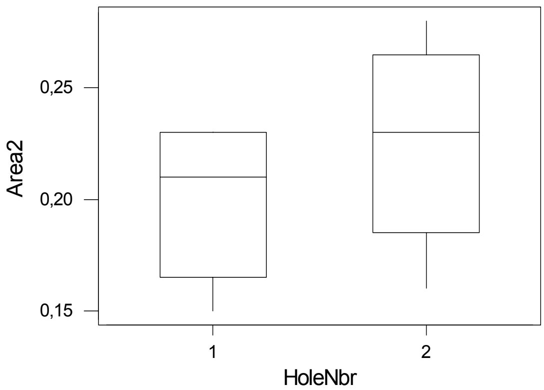
All holes were possible to detect in the light test. The results are displayed in box plots, illustrating measured area [Graph 5.1], measured total luminous [Graph 5.2] and finally the result from the rotated sample are displayed [Graph 5.3]. The two first box plots show that both the measured area and total luminous differ between the different sizes of the holes. This is confirmed by the statistical analyse which shows that there is a significant difference between the four smallest holes. However it is not possible to see a significant difference between the two biggest holes. It is though important to pay attention to that the two diameters only differ with seven percent.
The rotated sample [Graph 5.3] shows that a rotation of the sample can have a small effect on the result. However this effect is not significant.



Graph 5.1 Box plot showing the measured area



Graph 5.2 Box plot showing the measured total luminous intensity



Graph 5.3 Box plot showing the measured area for the two biggest holes measured with sample placed at different angels

5.4 Conclusions

The result demonstrates that it is possible to detect all holes in the aluminium layer, at least for the sizes we have tested (down to 0,075mm^2). It is also possible to compare the sizes of the holes. Even though it is possible to see differences between different sizes of holes we have not found any good regression line that describes the relationship. We make the conclusion that the light test has to be further developed if this should be possible. One reason for the error in the experiment is probably that we had problems making the samples identical (the size of the holes varied).

Nevertheless to succeed in our work we do not need the regression line, it is enough if we can compare the size and therefore which one is the better of two holes.

Notable is that it is important that the samples are placed equally in the light test to reduce the error.

6 Problem areas

- Where in the bottom folding is it most common that cracks in the aluminium foil appears
- How large are the cracks at the different places

6.1 Goal

The first test was not only initiated to investigate different measurement methods. The test was also performed to increase the knowledge of the bottom's weaknesses:

- Where are the problems located?
- How severe are the problems?
- Why do the problems occur?

6.2 Procedure

The pictures taken during the light test are analysed with Optimas 6.51 [Figure 4.2]. Points of interest are named after their positioning [Figure 6.1] and the leaks connected to these points are recorded.

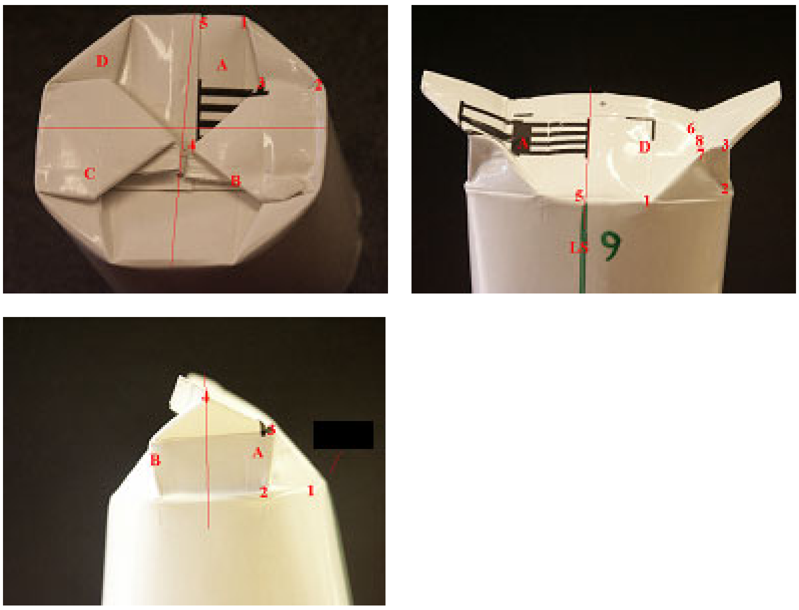


Figure 6.1 Interesting points and their name codes

6.3 Result

By looking at the results [appendix 2] and especially the graph showing luminous intensity for unfolded packages [Figure 6.2] certain problem areas can be observed:

- Area B6 and C6
- Points located on the same side as the LS (A1, A2 and D2)

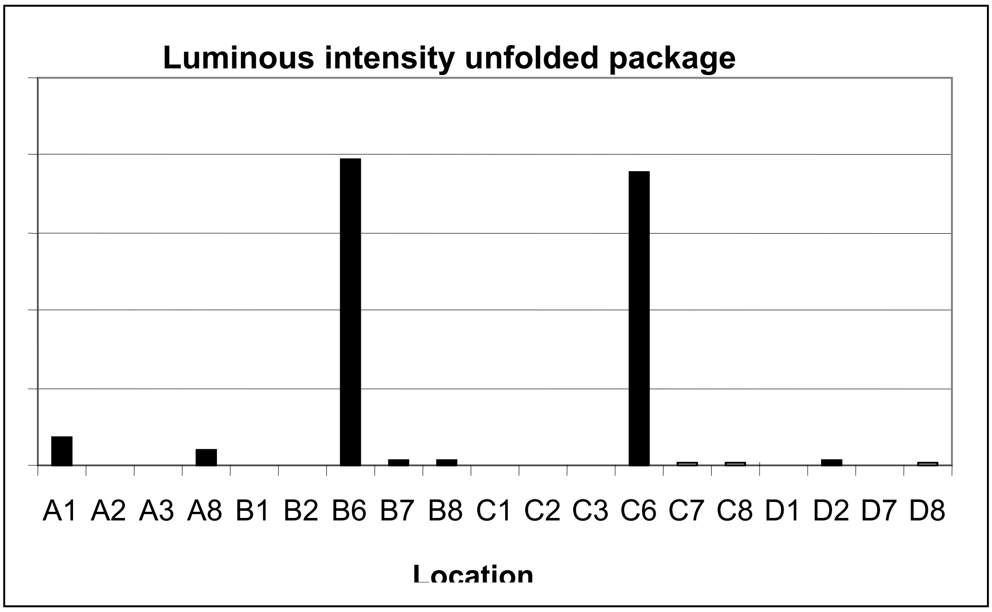


Figure 6.2 Luminous intensity at different points unfolded packages

6.4 Conclusions

The luminous intensity is by far the strongest at B6 and C6. Almost every package have problem at these two areas [Figure 6.3]. This is no surprise since this area, called the k-crease, already is known to cause problems at other Tetra Pak packages with similar folding pattern.

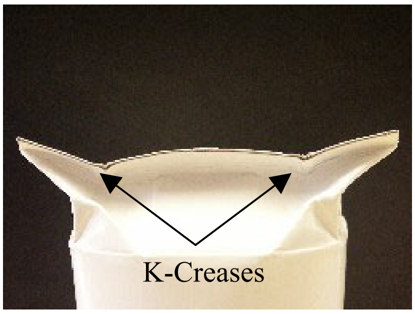


Figure 6.3 Location of the K-Creases

The problem appears due to heavy folding, which means that great tension arises in the aluminium foil. The bottom is created basically in three steps [Figure 6.4]:

- The TS is created by inducing electricity through the aluminium foil. This causes the inner plastic layer to melt.
- The TS is folded away from the LS and the extra material creates two triangular shaped end zones.
- The triangular end zones are folded towards the middle

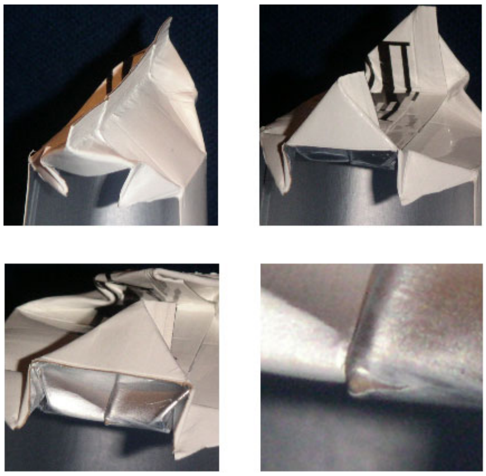
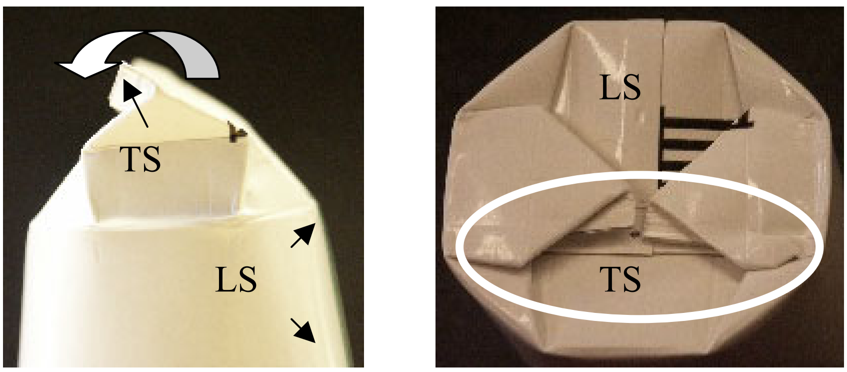


Figure 6.4 Crack propagation due to folding

The second problem is that points on the LS side seam to be at higher risk for cracks then points on the opposite side. This can be explained by the fact that the TS is folded away from the LS side and therefore creates a material build up on this side [Figure 6.5]. More material means better ability to withstand the force from the final plunger and the opposite, less material, means higher stresses in the material[18].



[18] Bengtsson Marie. Project leader. Tetra Pak R&D AB. 030409

Figure 6.5 Folding the TS away from the LS. Extra material circled

The problem with the points on the LS side is marginal compared to the problems with the k-crease. This is why we from now on focuses only on solving the k-crease problem.

7 K-crease theory

- A theory that describes why k-cracks appears
- A conclusion of what should be done to reduce the k-cracks

7.1 Goal

As mentioned earlier the problems with cracks in the aluminium foil at the k-crease appear due to heavy folding in this region. But why is heavy folding risky and what can be done to decrease these problems?

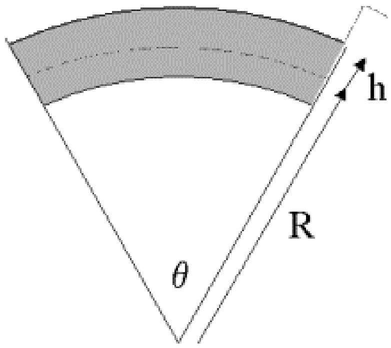
7.2 Problem

When folding the k-crease the aluminium foil will be stretched around the paper layer due to its orientation, but it will also be forced to fold around two full material layers that derive from the folded TS [Figure 7.1]. That is why the aluminium foil collapses.

Figure 7.1 Cross section of the k-crease where the outer aluminium foil is folded over three layers of material

7.3 Assumption

Folding the material can be approximated with bending a beam. However the formula [Equation 7.1] for bending a beam is built up on the assumption that the beams entire material is elastic. The cross section [Figure 7.2] reveals that this is not really true for the entire material. The inner layers get compressed but the formula is still giving a good view of how the parameters are affecting the tension in the outer aluminium layer.



$$\sigma = E \cdot \varepsilon = E \cdot \frac{l_1 - l_0}{l_0} = E \cdot \frac{\theta \cdot (R + h/2) - \theta \cdot R}{\theta \cdot R} = E \cdot \frac{h/2}{R}$$

$$\Rightarrow \sigma \sim \frac{1}{R} \sim h$$

Equation 7.1 Formulas describing how the tension depends on R and h.

7.4 Conclusion

This means that the tension in the outer aluminium layer can be reduced in two ways:

- Increasing the radius, R [Figure 7.2].
- Decreasing the thickness, h (a conclusion also drawn by R Cetrelli[19]).

However increasing the radius will lead to a thick bottom on the TS side and hence an unstable package. Left is therefore decreasing the thickness. This can perhaps be done by changing the fold pattern, crease pattern, preheating the k-crease or using other materials.

[19] *K-bigsprickor. big för undvikande av K-bigsläckage I Brikförpackningar.* Cetrelli Renato. 790515

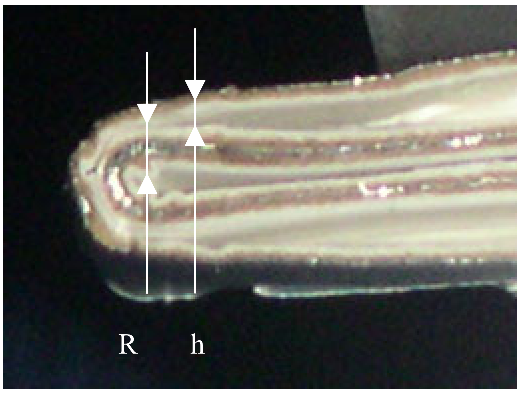


Figure 7.2 Cross section of the k-crease with the radius, R, and the thickness, h, displayed

8 K-crease

- Theory about different crease types and crease patterns
- A single comparative experiment to increase the knowledge about different crease types
- A multifactor experiment to find the optimal crease/fold pattern

8.1 Generally

As described in the theory we are interested in decreasing the thickness of the material at the k-crease. Two ways of doing so will be examined during this chapter:

- Changing the fold pattern.
- Changing the crease pattern.

Our idea is either to narrow or remove the material that the triangular shaped end zones is folded around. This can be done in several ways, but the ways we looked at could be divided into three groups:

- Make the TS fold as narrow as possible using a different crease type.
- Remove the material using a different crease pattern.
- Remove the material using a different fold pattern.

8.2 Suggestions

8.2.1 Crease type

8.2.1.1 Crease type A

The crease type A helps the critical fold to get thinner/sharper, at the critical area, compared to a normal crease. The Crease type A enables the collapsed paper material to assemble of centre and therefore the fold gets thin/sharp.

8.2.1.2 Crease type B

The dies that punch a crease type B shear the material on three places. That is one more then for a normal crease, which may affect the material's RCS[*] value, which becomes really low[20]. This means that its fold could posses the qualities searched for and therefore be suitable. Another interesting view is the opportunity to combine this crease in other patterns.

8.2.1.3 Crease type C

There is no clear theory behind the crease type C but there are some results that have been noticed[21]. Crease type C has resulted in lower RCS values and a sharp edge while the external folding is convex and not concave as for normal creasing [Figure 8.1]. This sharp edge will probably increase the tension of this aluminium layer but if the layer can endure this tension this will improve the conditions for the outer aluminium layer.

[*] RCS: Relative Crease Strength is a value on the force needed to fold a creased compared to an uncreased sample to a certain angle

[20] Louman Theodor. Development Engineer. Tetra Pak Converting Technologies AB. 030429

[21] *Crease Project CMT Brasil* Tetra Pak Ltda,. Brazil 020730

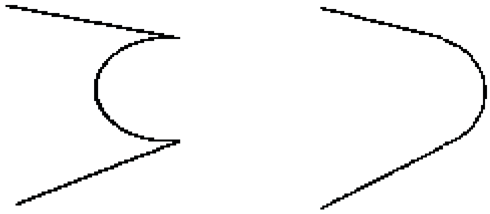


Figure 8.1. L: concave R: convex

8.2.1.4 Crease type D

The idea is from Tetra Recart where the special production process could not handle any kind of extra creases as for example the crease type A[22]. To improve the robustness they tried to use a Crease type D.

8.2.2 Crease pattern

8.2.2.1 Crease pattern X

The Crease pattern X is already used on other Tetra Pak packages where k-crack has been a problem. The idea with crease pattern X is to force the inner material layers to bend away from its normal position, this without disrupting the shape of the package [Figure 8.2]. By doing so the problem with folding around three layers will be reduced to folding around only one layer. The angle/ratio that there should be between A and B is determined by looking at drawings used for Tetra Brik 1000ml[23].

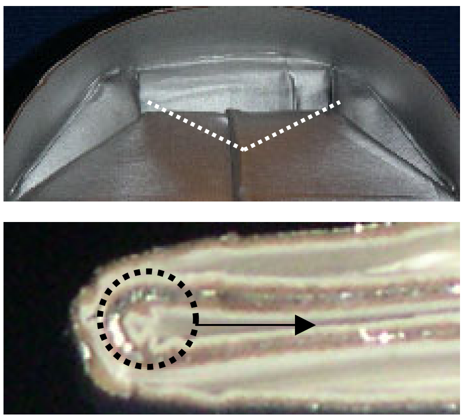


Figure 8.2 Moving the inner material layers

[22] Lindsjö Ulf. Development Engineer. Tetra Recart AB. 030424
[23] Louman Theodor. Development Engineer. Tetra Pak Converting Technologies AB. 030506

8.2.2.2 Crease pattern Y

To further control the folding and therefore also make the inner layer thin/sharp crease pattern Y could be used

8.2.3 Fold pattern

8.2.3.1 S-fold

To reduce the amount of paper layers that the outer aluminium layer is folded around the folding pattern can be slightly adjusted. Changing both the crease pattern in the critical area and changing the folding process in the final folding machine do this.

A small pre-test that we made on this new fold pattern showed promising results

The benefit by changing the folding is that nearly all paper from the TS disappears from the critical area. This strongly reduces the tension in the outer aluminium layer. It is also possible that the package will be more stable while the elastic deflection is reduced which make the bottom thinner.

All these suggestions will be tested. However designing a multifactor test based upon all the suggestions will be large even if it is reduced. Therefore we start up with testing which crease type is most suitable in a single comparative test. This will determine which crease type will be used in the multi factor experiment.

8.3 Type of crease (single comparative test)

8.3.1 Goal

The main goal with the test was to find out which crease type can be folded the thinnest. The test was also launched to expand our knowledge about different types of creases. Where does the material collapse? What are the RCS values of different creases? We looked closer at:

- Crease type A
- Crease type B
- Crease type C
- Crease type D
- Normal crease (used as a reference)

8.3.2 Procedure

Each of the crease types is punched with small plastic dies [Figure 8.3-4]. These dies are drawn and manufactured using ProEngineer and a 3-D plotter. The creases were punched on 10 mm narrow material samples. There were two orientations of the samples' creases: cross direction and machine direction. 20 samples where made in each direction and for each crease type.

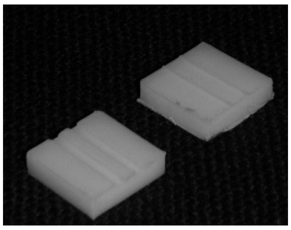


Figure 8.3 Male and female die used to punch a crease type A

The samples where then divided into to equal halves. One half was used to measure the RCS value while the other half was folded in a paper and carton folder. The thickness of the folded samples was then measured.

Figure 8.4 Device used to punch creases

8.3.3 Result

The test showed that it was not possible to see any difference in RCS values between the MD (Machine Direction) and CD (Cross Direction) direction. However it was possible to see a difference [Figure 8.5] between the three types of creases (crease type D is not analysed with RCS). A closer comparison of crease type B and crease type C against normal crease showed that the difference was significant [Table 8.1]. The lowest RCS value was found at the crease type B followed by the crease type C and finally the highest value for the normal crease.

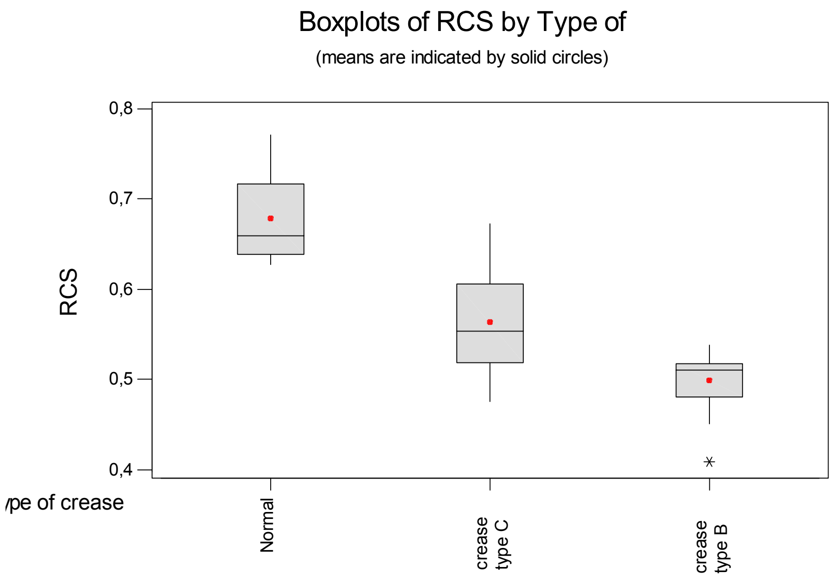


Figure 8.5 Box plot showing RCS value for different types of creases

```
Level        Lower     Upper  -+---------+---------+---------+------
Type C   -0,14864  -0,08152                     (--------*---------)
Type B   -0,21318  -0,14606  (---------*--------)
                             -+---------+---------+---------+------
                             -0,210    -0,175    -0,140    -0,105
```

Table 8.1 Table showing RCS confidence interval of crease type C and crease type B minus normal crease (confidence interval below or over zero mean significant difference)

There was no significant difference in thickness between creases in the MD and CD direction. It was however possible to see a difference between different types of creases [Figure 8.6]. A closer comparison [Table 8.2] illustrated that both the crease type A and the alternative crease type D showed significant differences of a thinner fold than the normal crease. Even the crease type B showed better properties but the result was not significant. Crease type C showed a thicker fold but the result was not significant.

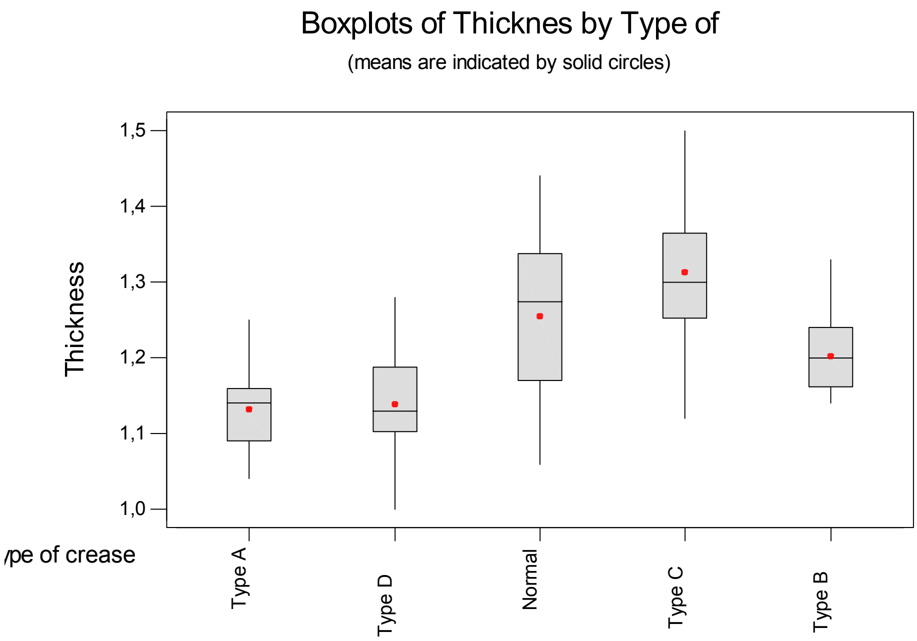


Figure 8.6 Box plot showing the thickness for different creases

```
Level         Lower      Upper ---+---------+---------+---------+----
Type A     -0,18295   -0,06405 (-------*------)
Type D     -0,17595   -0,05705  (------*-------)
Type C     -0,00195    0,11695                      (------*-------)
Type B     -0,11245    0,00645          (------*-------)
                               ---+---------+---------+---------+----
                               -0,160    -0,080     0,000     0,080
```

Table 8.2 Thickness confidence interval of the different crease types minus normal crease (confidence interval below or over zero mean significant difference)

8.3.4 Conclusions

Crease type B has the lowest RCS value. This ability makes it easier to get the folds in the right position. It will also make the folds sharper, which will lead to a better-looking package. The most important result was that the crease type A and crease type D both gave a significant lower value regarding thickness than a normal crease.

It is interesting that it was not possible to separate crease type A, from crease type D, neither with the photos nor with the measured thickness. It looks like the crease type A actually behaves like crease type B in the fold at the critical area. We believe that the crease type A as a matter of fact only shows an improvement because there appears an crease type D area in the critical area. We have not found any report[24,25] or test results that support our theory but we have neither found anything that talks against it. Cetrelli's tests[26] only compare the crease type A with a normal crease, not with an crease type D fold.

8.4 Type of crease/fold pattern (multi factor test)

8.4.1 Goal

This test was carried out to find the optimal combination between crease type and crease pattern. The goal was to find what combination that gives the smallest cracks in the k-crack zone.

8.4.2 Procedure

We found that three of the changes suggested were worth working further with. The test was planed as a multifactor experiment with these three factors. Every factor was tested at two levels (on / off). We found the risk for two and three factor interactions low and therefore the test was reduced one time (2^{3-1}) to save resources. Parallel with the multifactor experiment the s-crease was tested. The material was creased at Odenprint. After the package was sealed and folded, the s-crease was folded by hand, the result was analysed with the light test.

8.4.3 Result

The result of the multifactor experiment can principally (the light test only shows a comparative size) be calculated with a formula [

Table 8.3] where the three factors are involved. However it was only Crease pattern Y that showed a significant result. The crease pattern X has a statistical security of 88 % that a difference really exists (we have defined significant difference as 95 %). Crease type A showed nearly no statistical difference (only 15 % security). The result from the s-crease test was compared with the optimal crease combination found in the multifactor test above. The comparison showed a significant difference of the crack size [Figure 1.17]. The packages with s-crease had approximately 80 % less cracks.

---

[24] *K-crack investigation*. Tetra Pak AB. 970912

[25] *K-bigs läckage vid olika typer av bottenbigar*. Tetra Pak AB. 810827

[26] D*ig för undvikande av K-bigsläckage i Brickförpackningar*. Tetra Pak AB, 790515

$$Crack = 7{,}2 + 1{,}2 \cdot PatternY - 0{,}7 \cdot PatternX - 0{,}1 \cdot TypeA$$

$$PatternY \begin{cases} -1 = nocrease \\ 1 = crease \end{cases}$$

$$PatternX \begin{cases} -1 = paralell \\ 1 = slanted \end{cases}$$

$$TypeA \begin{cases} -1 = nocrease \\ 1 = TypeA \end{cases}$$

Table 8.3 Formula for calculation of crack size

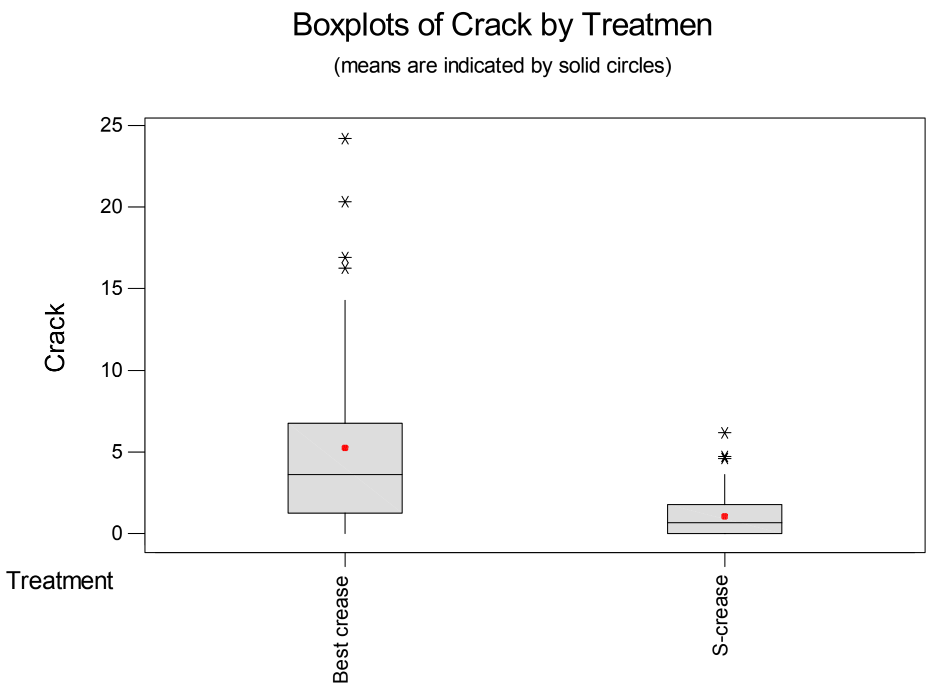


Figure 8.7 Box plot of Best crease versus s-crease

8.4.4 Conclusions

The multifactor experiment shows that crease pattern Y is not a good solution to reduce cracks. Crease pattern X seem to reduce the cracks even though it is not really a significant difference. According to our test there is no difference between crease type A and crease type D, which is exactly the same result that we had in the pretest. The s-crease test shows again that the crack size is strongly reduced on these packages. This seems to be the improvement that improves the packages robustness the most.

9 Testing of preheating and paperboard thickness

- Theory about the effect of preheating on the k-crease
- Theory about the effect on the k-cracks when using different qualities of paperboard
- A multifactor experiment with preheating, thicknesses of paperboard and crease pattern as factors

9.1 Generally

Tetra Pak was interested in testing what happens when a different thickness of the paperboard is used compared to the one used today. The two paperboard materials were Korsnäs duplex clc/c150mN and Korsnäs duplex clc/c 260mN. They also wanted to see if preheating was a good solution to the k-crack problem. Our theories about the two solutions are:

A thicker paper layer leads to a larger thickness, h, according to the theory about k-cracks in the k-crease theory chapter. This means that the outer aluminium foil will be exposed to higher tension and therefore the risk for k-cracks will be increased.

Earlier studies[27,28] have shown that preheating of the k-zone has decreased the size and numbers of cracks. This idea is also patent pending[29]. Heating up the paperboard makes the whole structure easier to bend and the E-modules lower for the total packaging material structure. What happens in the different layers is listed below.

- The paperboard is built up of different elements. These are: lignin, hemicelluloses and cellulose. The different parts will be softer at different temperatures. This temperature is called Tg and is depending on the moister level in the material. Lignin has a Tg temperature of approximately 72-128°C, hemicelluloses approximately 54-167°C and cellulose somewhere around 240°C. Earlier practical experiments[30] have confirmed that heating the material to somewhere between 80 and 250°C makes the paper board soft and easy to bend.
- The polymers will be softer and have increased elongation properties. They will loose some of their tensile strength. They will also loose some of their sealing properties and this leads to delaminating in the material.
- Aluminium will be little affected on the relatively low temperatures.

9.2 Goal

This test was made to see how the k-cracks in two different paper qualities are affected by preheating and different crease pattern. The paper qualities differed in the thickness of the paperboard layer but not in the other layers. Preheating was tested at three levels, one level without heat and two levels with different temperatures. Two types of crease pattern were tested, the ordinary pattern and the one we have optimised regarding the last multifactor test.

[27] *Pre heating to reduce K-zone cracks and avoid K-zone leakage's*. Tetra Pak AB, 010517
[28] *Pre heating-reduction of K-crack.* Tetra Pak Ambient AB, 030228
[29] Patent pending TP1354
[30] Patent pending TP1354

It was of interest to see if the two materials react similar or different to the different treatments. It was also interesting to see if the size of the k-cracks differed between the two different thicknesses.

Parallel with these two tests the s-fold was tested on both paperboard qualities but without preheating.

9.3 Procedure

Two different paper qualities where creased at Odenprint. Each package was creased with two different k-creases: the existing and the optimised. The final folding machine was rebuilt so that a preheater was added in the step just before the critical fold was made. The preheater was set to blow hot air at three levels: no heat, 400 and 700°C. An IR-thermometer was also added so that the temperature on the outside of the package could be measured

The packages were put in the final folding machine after being LS sealed. In the final folding machine the packages were folded with different settings on the preheater. The s-fold was made by hand as in earlier experiments.

The packages where then tested in the light test and the result was statistically analysed with Minitab 13. The results from the light test had to be recalculated for the thicker paperboard. This recalculation was made because less light trickles through a 260mN paperboard layer.

9.4 Result

During the experiment the temperature on the outside of the package where the preheater was blowing hot air was measured to aproximately105°C when the preheater was set at 400°C and approximately 130°C when the preheater was set at 700°C.

The result [Figure 9.1] showed that the leakage was significantly affected by two factors: heat and thickness. It also showed that there was an interaction between these two factors. By looking closer to this result we found that the significant difference in cracks between the two thicknesses of the paperboard only appeared due to preheating. When no preheating was attached to the packages there was hardly any difference between the two thicknesses. The thicker paperboard showed slightly larger cracks but there was no significant difference.

The interaction [Figure 9.2] between heat and thickness of the paper shows that the 150mN paper was affected extremely negative to heat while the 260mN paper was less affected at least at low heat.

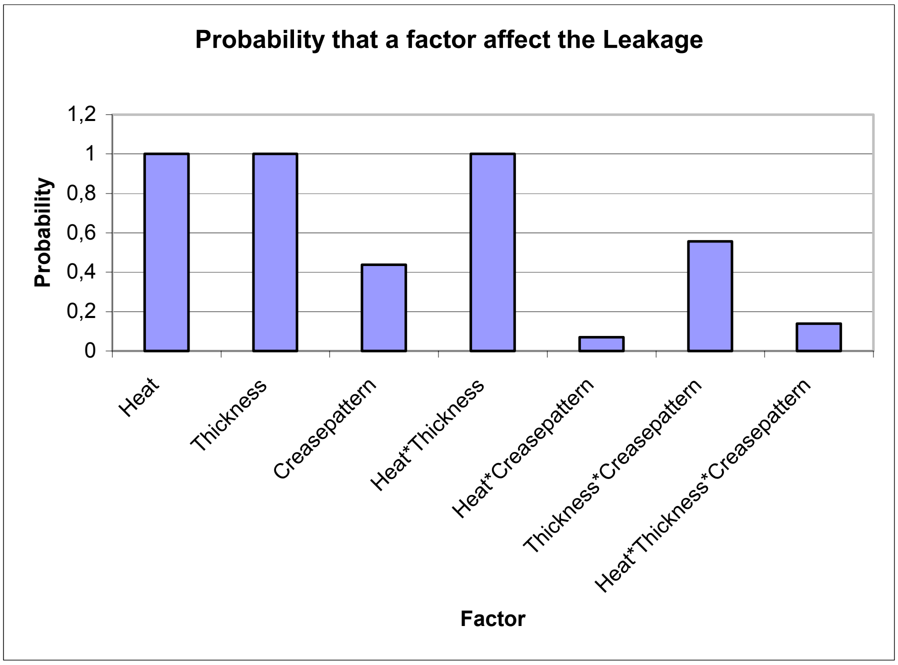


Figure 9.1. Probability that a factor affect the leakage

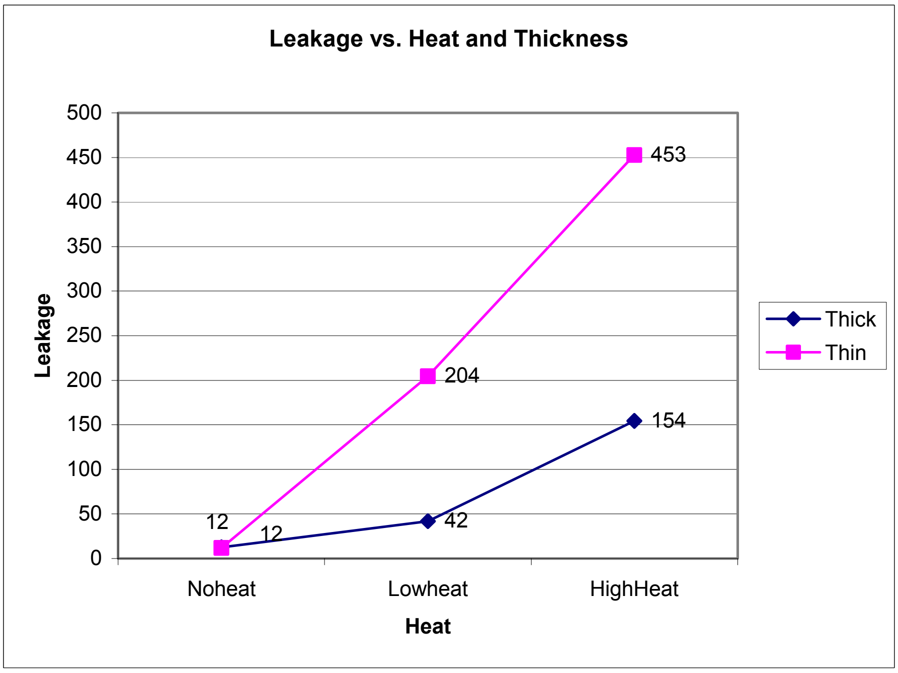


Figure 9.2 Leakage versus Heat and Thickness

The crease pattern had a small effect on the leakage but it was not significant [Figure 9.3]. It could however be mentioned that there was less leakage in those with the optimised crease pattern. We have chosen to only show the comparison between the two crease patterns when the preheater was set on no heat. The leakage was so large at the packages that were affected by heat that it is impossible to make any conclusion about the effect of the crease pattern.

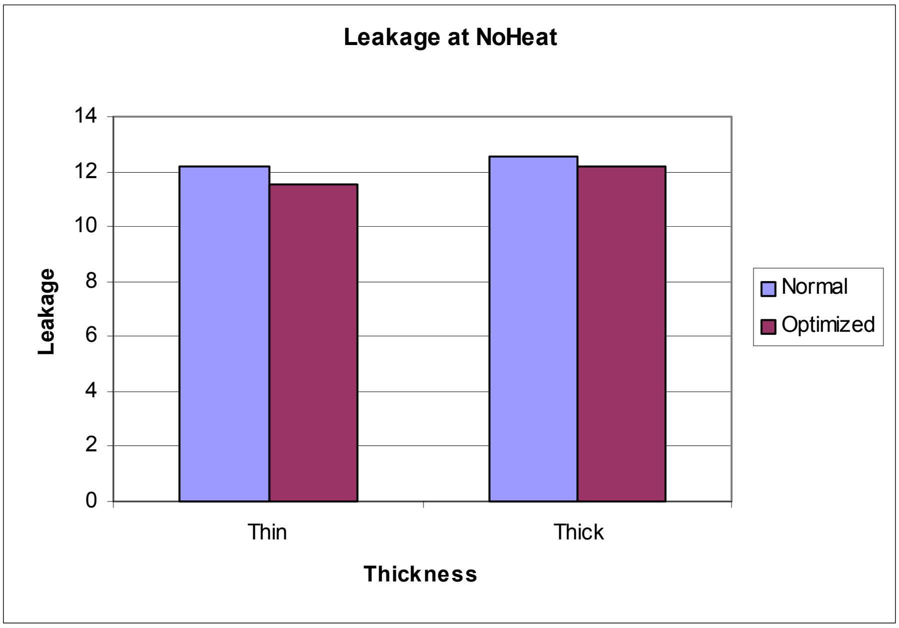


Figure 9.3 Leakage normal crease pattern versus optimised crease pattern

There were only seven out of 50 packages that had leakages in the k-zone among the packages with the s-fold. This means that there is a significant difference between s-fold and the normal fold for both thicknesses [Figure 9.4-5].

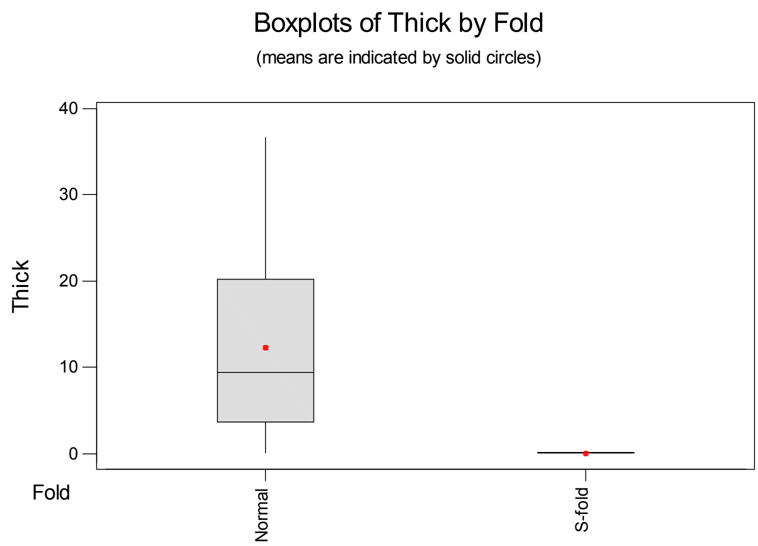


Figure 9.4 S-fold versus normal fold on thick paper

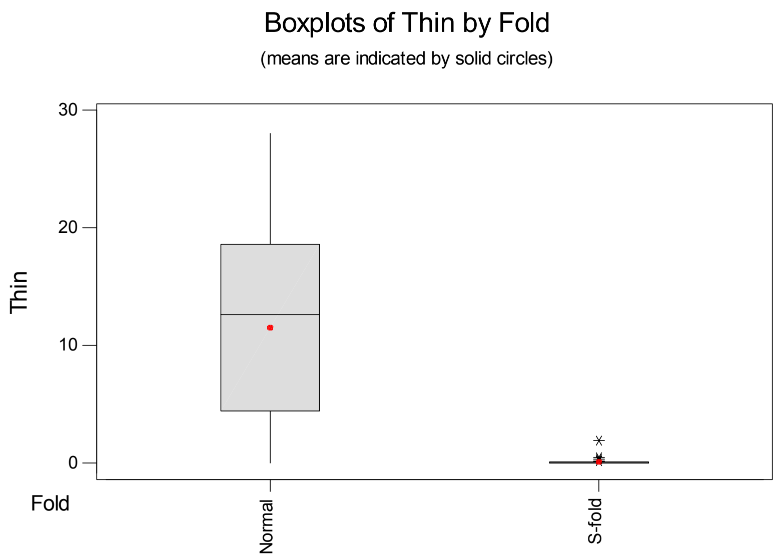


Figure 9.5 S-fold versus normal fold on thin paper

9.5 Conclusion

The result was not totally as we had expected. In our research the result of preheating had turned out to be positive regarding k-cracks and that was not at all what happened now. Two possible reasons for this are:

- The heat was to strong so all the moister in the paper layer was forced out. Low moister level has in earlier tests led to larger cracks. This because the fibres get porous.
- The inner plastic layer that is attached to the aluminium may have melted so that it has lost all its tensile strength. The aluminium foil has then to withstand all tensile strength by itself, which could be a reason for the big k-cracks.

These conclusions are based upon earlier observations that we made when we started to investigate preheating and the fact that the thicker material not has been so badly affected as the thinner material. One reason for this can be that the inner layers have been affected less by the heat since the thicker paper has an isolating effect.

An explanation to why the optimised crease pattern showed very little effect and not a significant positive effect can be bad adjustments of the final folding machine. For getting the best result of the crease pattern it is of importance that the fold is made in exactly right position. It should also be mentioned that the crease pattern is a relatively small adjustment and the result is not affected as extremely as for example by the s-fold. It is however important to notice that the optimised crease pattern has been better in all tests even if the difference was not very big.

The explanation to why the thickness of the paperboard did not significantly affect the k-cracks can be that the radius, R, which is described in the k-crack theory chapter has increased for the thicker paperboard. This means that the tension in the outer aluminium layer will be lower but also that the fold will get thicker. During the manufacturing process we noticed that several packages were unstable due to this problem.

The s-fold showed very good result with hardly any k-cracks. It has also the benefit that the packages stand more stable because of the thinner fold.

10 Conclusions and further proposed investigations

- Conclusions from the entire dissertation
- Proposals for further investigations

10.1 Weaknesses

We found that the biggest cracks appeared in the k-zones and therefore we decided to focus only on improvement of these cracks. When the k-crease problem is solved it would be reasonable to work with other cracks, such as the cracks on the LS side.

10.2 Crease pattern

The creases have two purposes. They help the folding machine to get the folds in the correct position and they are also used to reduce cracks in the material. It is very important that the machine is precise in the way it folds the packages if the creases should have the right effect. The existing final folding machine is not very precise and this has probably affected our results. We have tested different crease patterns and different crease types that are known within Tetra Pak. Our results show that it is possible to reduce the k-cracks by using an optimised crease pattern but the improvement is quite small. One interesting result we found was that on other packages the common used crease type A not was any improvement compared to an crease type D alternative. We believe that the crease type A as a matter of fact only shows an improvement, compared to a regular crease, because there appears an crease type D area in the crease type A. We have not found any rapport[31,32] or test results that support our theory but we have neither found something that talk against it. Cetrelli's test[33] does only compare the crease type A crease with a normal crease and not with an crease type D.

10.3 Folding

All our tests have shown that a small change in the folding of the package has led to very good improvement of the k-crack problem. The packages that have an S-fold have nearly no leakage compared to the packages with the TS folded the existing way. Even if no measurement has been done we have also noticed that these packages, due to a thinner and more even material contribution, tend to be more stable. It has late in our work come to our attention that this in fact was known within Tetra Pak in 1980. However it has been forgotten and has remained unused. According to the inventor[34] of the s-fold the reason for this was that the crease type A appeared at around the same time and one of the two solutions had to withdraw. According to our test the s-fold is a much better solution while the crease type A has a more marginal effect. The disadvantage with the s-fold is that the final folding machine has to be changed a bit. This change has already been tried and done on a Tetra Brik machine according to the s-fold inventor, who also claims that the change was not big and that it worked properly. We find this solution very interesting to investigate further. The fact that this improvement can be used on all Tetra Pak

[31] *K-crack investigation*. Tetra Pak AB 970912
[32] *K-bigs läckage vid olika typer av bottenbigar* Tetra Pak AB. 810827
[33] Big *för undvikande av K-bigsläckage i Brickförpackningar*. Tetra Pak AB., 790515
[34] Löthman Stig A. Tetra Pak AB (retired). 030815

packages (such as Brik, Top and Prisma) with K-cracks problem makes it even more interesting to further investigate.

10.4 Light test

It has been shown that the light test as a measurement method in a powerful tool. It can be used to discover and locate cracks in the aluminium foil. There is another method that is similar to the one that we have designed and used. However the problem with the other method was that it worked under a constant light that either burned the packages or missed out on finding smaller cracks. Our method with a flash solves this problem. We have also used the light test to compare sizes of cracks, which works very well. However it is not possible for us to quantify the cracks with this method. Still we believe that this test can be further developed and standardized which probably will make it possible to quantify cracks.

10.5 Preheating

Our result from the preheating test showed, not as suspected, that heat significantly increased k-cracks. This is opposite to earlier results[35] and even if we have looked for explanations to this both in the temperature used and in the fact that we used a slightly different material we still have not found any reasonable explanations. Our suggestion for future work will firstly be to redo our experiments and try to find out what went wrong. It can also be recommended to try and gain more understanding of the process in the material.

10.6 Thickness of paperboard

We found no significant disadvantages with the thicker paperboard but on packages with small bottom areas the thicker TS fold probably will make the package unstable.

[35] *Pre –heater*. Tetra Pak Ambient AB. 030311

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11.2 Internal literature

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K-bigs läckage vid olika typer av bottenbigar. Tetra Pak AB. 810827
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Pre heating-reduction of K-crack. Tetra Pak Ambient AB, 030228
Pre heating to reduce K-zone cracks and avoid K-zone leakage's. Tetra Pak AB, 010517
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Crease Project CMT Brasil Tetra Pak Ltda,. Brazil 020730

11.3 Personal communication

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Louman.Theodor Development Engineer. Tetra Pak Converting Technologies AB. 030429
Louman Theodor. Development Engineer. Tetra Pak Converting Technologies AB. 030506
Löthman Stig A. Tetra Pak AB (retired). 030815
Nilsson Christer. Development engineer. Tetra Recart AB. 030304

11.4 Electronical sources

http://www.matweb.com MATWEB, material property data, 030828

Appendix 1: Light test description

Scope

Light test is used to detect cracks in the aluminium foil. Aluminium foil works as oxygen and light barrier. If light is penetrating the package it means that there exist cracks in the Aluminium foil. The test is built upon the principle of putting a strong light source into the package and see if there is any light visible from the outside. The test is usable for all kinds of packages with Aluminium layer and for plane smaller material samples with aluminium layer.

Significance and Use

This method is used to detect where cracks in the aluminium layer exist. It is also possible to compare the cracks different sizes.

Test Equipment

- Camera (digital camera preferable)
- Free standing flash
- Dark tube
- Platform for the package
- Mirrors
- Picture analyse program (for example Optimas 6.51)

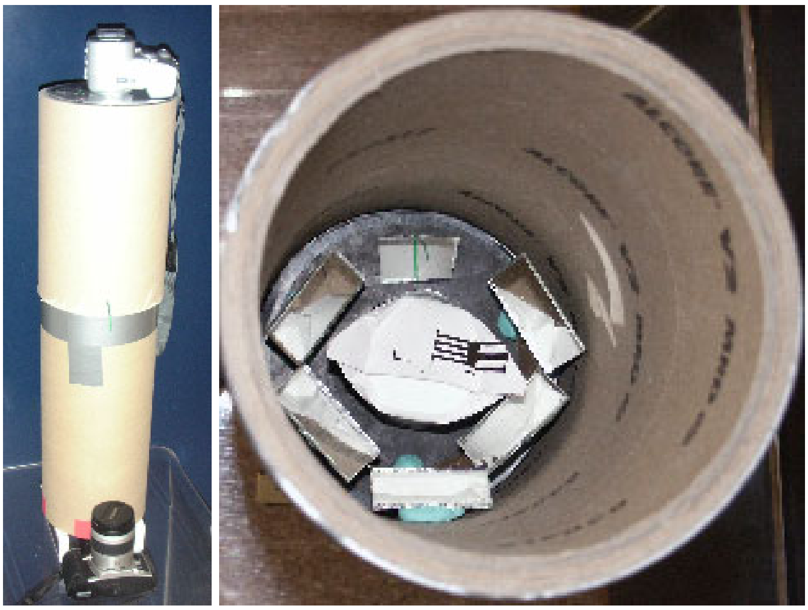


Figure 1:1 Set up of test equipment seen from the side and from above.

Preparation of test equipment

Preparation of tube:

- Put the flash in the bottom
- Put the Package platform above the flash
- Put the mirrors on the platform so that they reflect the critical parts of the package that is not possible to see from above
- Put the camera on the top of the tube

Preparation of camera equipment:

- Adjust the focus and zoom so that the picture shows a clear picture of the whole package.
- Synchronize the flash and the camera or set the camera at a long exposure time so that the flash can be started off manually during the exposure time.

Preparation of picture analyse program:

- Adjust the settings in the picture analyse program to make sure that it detect the light spots that comes from lights passing through the package.

Preparation of samples

Depending on the platform the test can either be performed on packages cut in parts or just plane material samples. The package is cut of at a plane parallel to the most interesting area. If the bottom for example is investigated the package should be cut of at a horizontal line. It is important that the tested part not contains any transparent plastic tops or other transparent parts. Depending on the shape of the package it is sometimes necessary to unfold the package. If the picture is unfolded it is very important that it is done very careful and that pictures are taken both before and after the package is unfolded. Plane material samples do not need any preparations.

Procedure

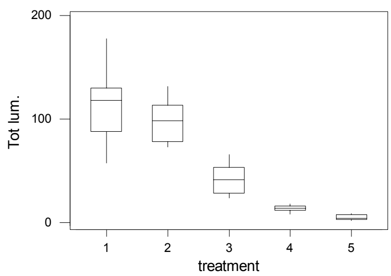
1. Place the prepared Package/sample on the platform and make sure that no light is leaking through between the platform and the Package/sample.
2. Take a picture with some light from above. This picture is made to make it possible to identify where the leakages takes place. It is optional if the flash is used here. If there are any big leakages they are possible to detect already on this picture otherwise it will only be an ordinary picture of the Package/sample.
3. Take a picture with the flash under the Package/sample without any light from above. It is important that the focus on the camera is locked otherwise there will be a problem for the auto focus to operate.
4. Transfer the pictures to a computer and analyse them.

Calculation

The total luminous intensity is calculated by multiply measured area and mean luminous. This procedure is done for every light leakage. To compare creases it is preferable to use a statistical analyse program such as Minitab 13.

Report

An example of how the results are presented follows below:



Graph 1:1 Total luminous intensity versus treatment (different hole sizes)

Reference Documents

Master Dissertation by Ewing Henrik and Lindgren Roger, Secure the robustness of a new carton

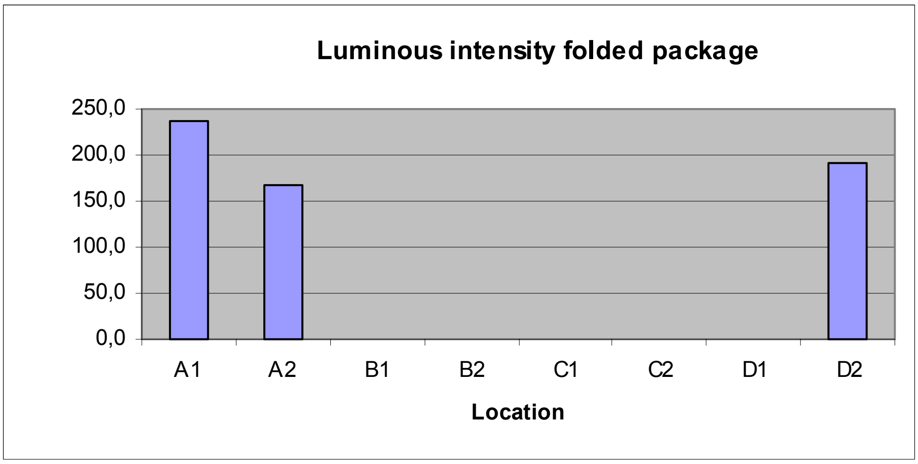
Appendix 2: Light test result

Points of interest folded packages

Table [Table 2:1] and graph [Graph 2:1] showing the location of interesting points and their luminous intensity given by the light test.

	Location								
Nbr	**A1**	A2	B1	B2	C1	C2	D1	D2	**Sum**
1		83,4							83,4
2	69,0								69,0
3								169,0	169,0
4								1,8	1,8
5	54,9								54,9
6								6,0	6,0
7		44,7						3,6	48,3
8	26,2	34,3						9,9	70,4
9	86,7								86,7
10		5,5							5,5
11									0,0
12									0,0
Sum	236,8	167,9	0,0	0,0	0,0	0,0	0,0	190,3	

Table 2:1 Result from light test on folded packages



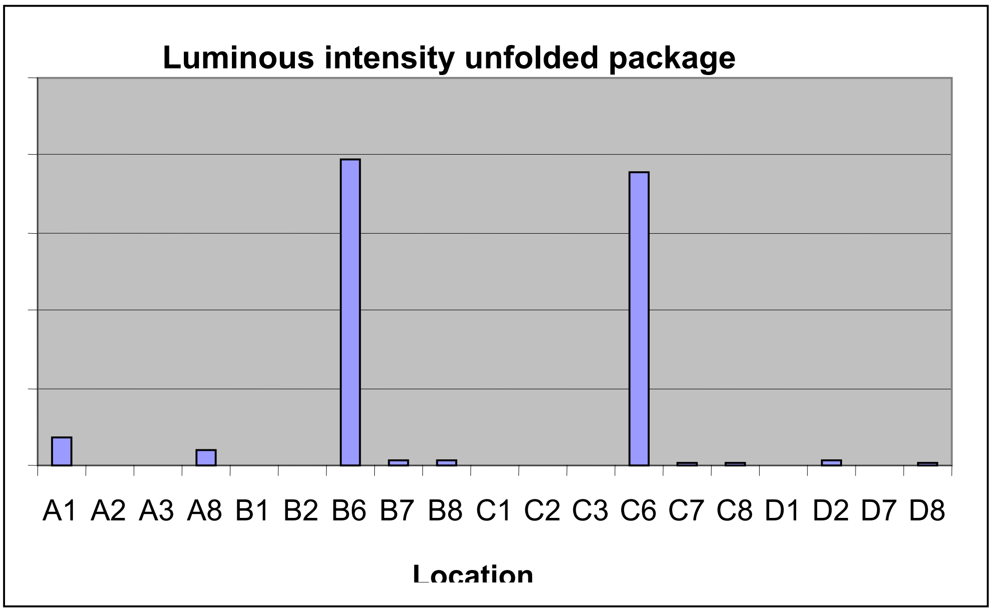
Graph 2:1 Result from light test on folded packages

Points of interest unfolded packages

Table [Table 2:2] and graph [Graph 2:2] showing the location of interesting points and their luminous intensity given by the light test.

	Location																			
Nbr	A1	A2	A3	A8	B1	B2	B6	B7	B8	C1	C2	C3	C6	C7	C8	D1	D2	D7	D8	**Sum**
1	827		32	450			4195		69		3									5574
2	135	61				31	3103	15						129						3475
3	402						2494						1152		203		14			4264
4													579				145		138	862
5	202			5			3265		7			12	4542							8033
6							269						492				248			1010
7				264																264
8	199	11					1698		229		19		7705							9861
9	29			12			2793		6				3066		37					5942
10		2			35		1425						366					44		1872
11				338			535	299		10			948			6				2137
Sum	430	74	32	1069	35	31	19777	314	311	10	21	12	18849	129	240	6	408	44	138	

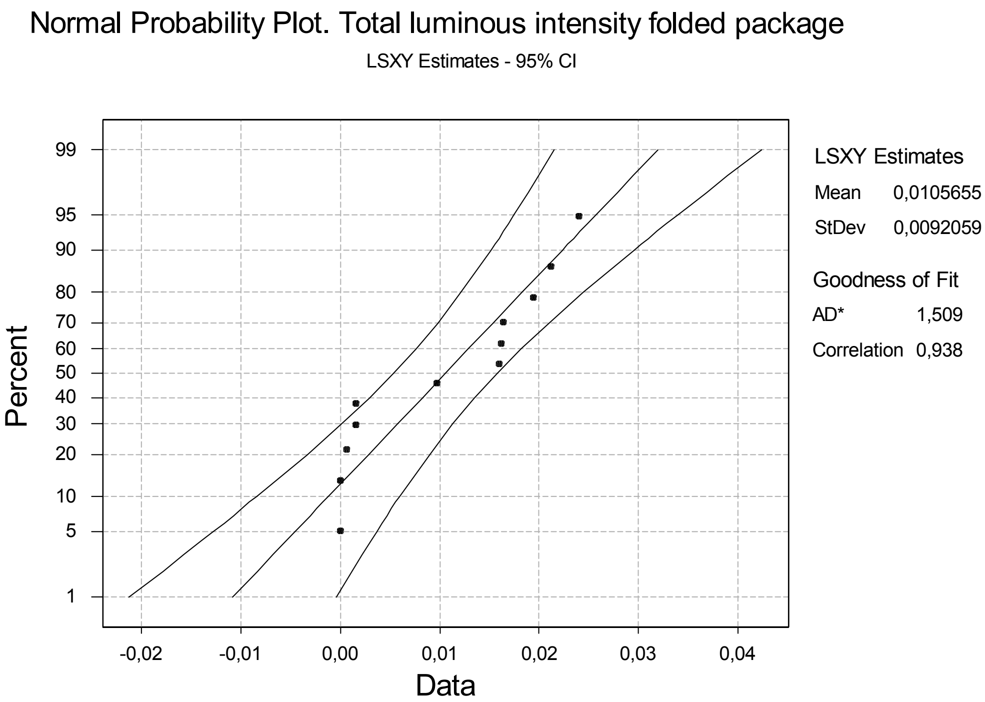
Table 2:2 Result from the light test on un folded packages



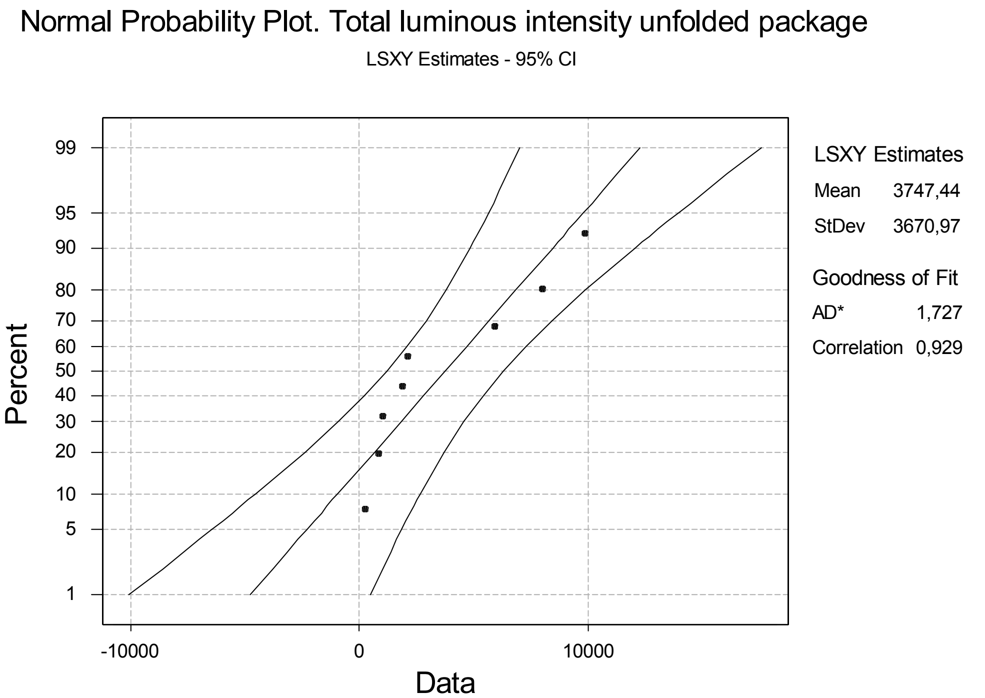
Graph 2:2 Results from the light test on un folded packages

11.5 Normal probability plots

Normal probability plots [Graph 2:3-2:4] of the results. If the results are normal distributed they should be close to the straight line. The area between the curved lines shows a 95% confidence level.



Graph 2:3 Normal probability plot of the light test result



Graph 2:4 Normal probability plot of the light test result

Appendix 3: S crease introduction test

K-crease folding

Introduction

The test is made to see if a change in the folding pattern has any potential to improve the package robustness and therefore is worth continuing working with. The goal is to reduce the crack in the k-crease zone.

The test rig

The new crease pattern is printed in a crease plotter. Two rulers are used to fold the paperboards.

Test description

Five examples of paperboards with the new crease pattern are printed in the crease plotter. Each example is divided into four parts. The four parts are attached to each other two and two and then folded by hand to simulate the folding machine in the k-crack zone.

The crack is measured with a magnifier glass.

Result

The result is displayed in the table [Table 3:1] and in the box plot [Graph 3:1].

	S-Crease (mm x mm)	Normal Crease (mm x mm)
1	0,6 x 0,2	3,6 x 0,4
2	1,1 x 0,2	4,8 x 0,9
3	1,3 x 0,2	4,5 x 0,5
4	0,5 x 0,1	4,0 x 1,0
5	1,0 x 0,2	4,5 x 0,6

Table 3:1 Result from the two treatments

Machine test

Goal

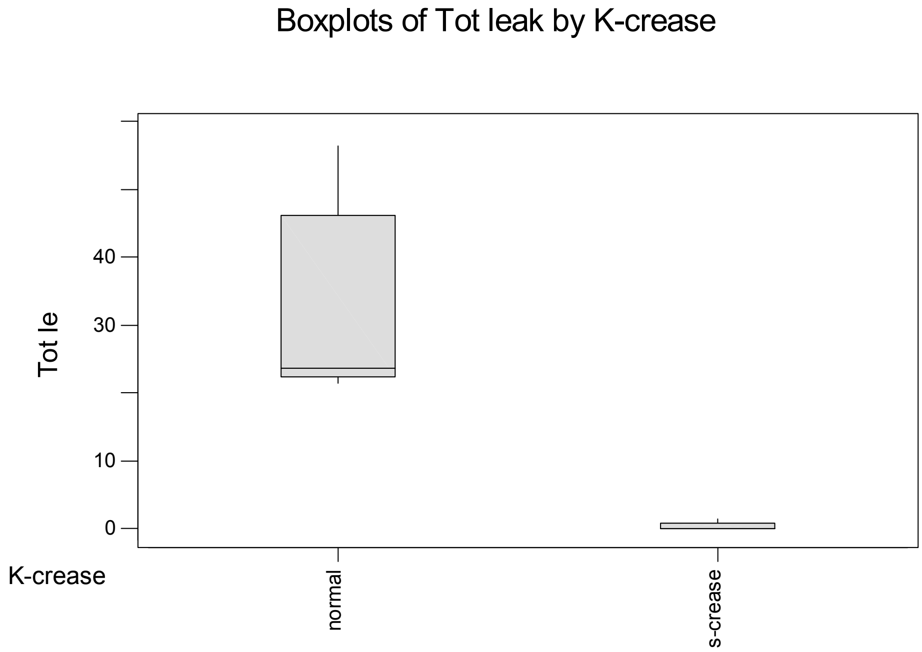
We have two purposes with this test. First we want to see how the s-crease works on a package, if the K-cracks will be reduced. Second we want to see what changes that needs to be done in the final folding machine.

Procedure

The test was made at precreased material. The extra creases that need to be done to make the s crease were punched by hand (in the same way as crease type were tested). Both ordinary packages and packages with s crease where mixed randomly in the machine. The ordinary packages served as references. No changes where made in the final folding machine. Instead the machine was stopped in one station where the package was changed by hand to make the s crease. The packages where analysed with light test and to check the K-cracks and visually checked due to package stability.

Result

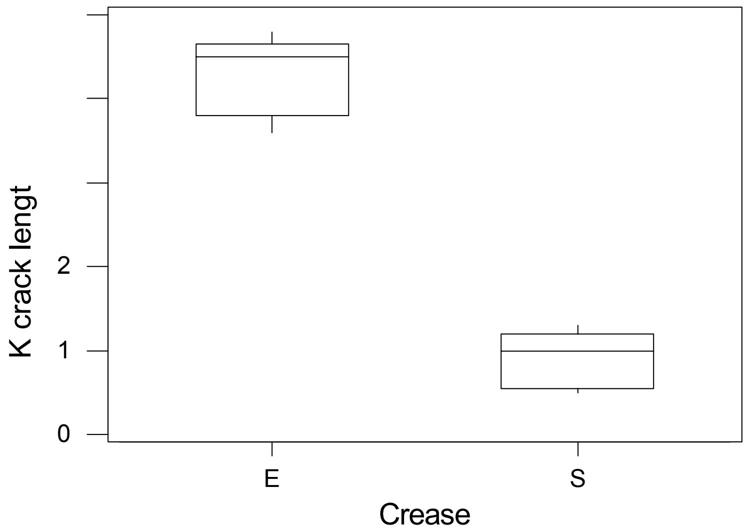
The analyse of K-cracks showed that they nearly disappeared in the packages with s crease. There was a significant difference compared to the ordinary packages. To simulate the work we made at the package by hand in the final folding machine an extra moving part need to be added. However it seemed possible just to change the geometry in one of the tools in the final folding machine. If this is possible the change in the final folding machine is very small to make the s crease.



Graph 3:1 Box plot showing K-crease measured with the light test

Conclusions

Our theory about the s these crease seems to correct. The K cracks are almost decreased to zero. It is also good to see that the change in the finally folding machine perhaps not need to be very big which make it easier to implement the change of the package.



Graph 3:2. Box plot showing the K crack length of the two treatments

Conclusions

The test showed a significant improvement of the k-crack. We also saw that the thickness of the fold was reduced.