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Qualification of Test Method for Package Perforation Evaluation

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By

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Abstract

The purpose of this paper was to develop a new test method for packaging perforation evaluation to replace the current test method due to the human variables during test and the inconsistency of test results. First, an end user survey was conducted to find out a typical opening pattern which was used by most of the consumers when opening the packaging perforation. Second, the typical opening pattern was further analyzed by an experiment. The opening process was recorded as videos and the relationship between displacement and time was analyzed in Matlab. It was found that the opening process of typical opening pattern was consist of horizontal direction movement and vertical direction movement. Third, a special fixture was developed based on the results of typical opening pattern analysis. The fixture was used with Instron tensile tester to perform the new test method. In order to validate the new test method, another experiment was conducted to compare results between new test method and typical opening pattern. It was found that the utilization of fixture had a great improvement for simulating the opening process of typical opening pattern.

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1. Introduction

CooperVision is one of the world's leading manufacturers of soft contact lens. It is founded in 1980 and its products are sold in over 100 countries and locations. Dedicated to continually bringing a fresh perspective to the contact lens experience for practitioners and patients, CooperVision specializes in lenses for astigmatism, presbyopia, and ocular dryness. The company routinely collaborates with eye-care professionals in the research and development of relevant products. CooperVision manufactures a full array of monthly and daily disposable contact lenses featuring advanced materials and optics.

Contact lenses are normally packaged in blister trays with solution as primary package. After that, a certain number of blisters are packaged into carton boxes as secondary package. Although contact lenses are medical device and regulated by FDA, they are more considered as “consumer products” because these products don't require a health professional for every use and consumers use on their own to solve health issues and improve quality of life. Thus, for the ease of consumers use, most CooperVision's carton boxes come with the same opening feature, which is perforation.

Figure 1.1 A part of Coopervision's product portfolio

Perforation is a cut in the paper material in order to be torn easily along the line, which provides convenience when customers open the package. When designing a package, package integrity is considered one of the most important factors as it ensures the protection of product, which could withstand the damage during packaging, handling and distribution process. However, the ease of opening is also a critical part of packaging design after products arrive at end users' hands because it enhances end users' experience by allowing consumers to open and use products in a more convenient way without using any tools. The beauty of the perforation design is that it can meet both requirements of packaging integrity and ease of opening.

1.1. Background

According to the latest packaging designs, there are two major perforation designs in Coopervision's products. One design is called top open, which has a perforated opening at the top of carton. The other design is called end open, which has a perforated opening at the side of carton. This paper mainly focuses on the study of top open design families due to the complexity of Coopervision's product portfolio.

Figure 1.2 An example of end open design

Figure 1.3 An example of top open design

When end users start to use products, they normally tend to open an intact package by tearing the perforations. This process is described as perforation opening process in this paper. There are always human variables during the perforation opening process because different people tear the perforations in different ways and it is impossible to ask customers to tear perforations in a 'standard' method. According to the facts and stats from American Optometric Association, over 30 million Americans wear contact lenses within different age and sex groups. The great variation within contact lenses wearers will result a huge variables when they try to open the package perforations. These variables could be different opening methods / force / speed, using left hand / right hand and various tearing directions, etc. Thus, a high quality perforation should always have a good performance to satisfy end users with all these variations.

Since perforation plays a really important role in Coopervision’s packaging design, there is necessity to have a perforation quality test to ensure that end users can tear perforations without any issues, whether they have different open methods / strength / speed, use left hand or right hand, tear in various directions, etc.

The current perforation quality test used in Coopervision is performed by human hands. Lab technicians will tear the packaging perforations by hand and visual inspect them. This process mimics the scenario when end users open the package, which gives an understanding if the perforations are easy enough for end users to open. From consumers' perspective, a high quality perforation should be torn along the perforated line as easily as possible while a poor quality perforation represents improper openings like hard to tear, tear won't go along the perforated line or delamination of paperboard. However, from packaging design standpoint, a perforation that is too easy to open might be too vulnerable to withstand the damage during the package assembly line, handling and distribution process, which may causes pre-openings before products reach customers. Thus, a successful package perforation design should be as easy as possible for all end users to open, regardless of their open methods, speeds, strength, left / right hands or open directions. While at the same time, it should be sturdy enough to protect the product during the packaging assembly, handling and distribution process and reach at customers with no pre-openings or other damages.

1.2. Problem Statement

However, one problem with the current perforation test is that there is no established test method or test standard. As a result, lab technicians may perform tests differently since they don't have detailed test steps or instructions to follow. After packaging perforations are opened, the package will be evaluated by visual inspection to see if there is any damage like unopened perforations, paperboard delamination or other damages.

Another problem with the current test method is that the results of packaging perforation tests are not reliable. This is because these tests are performed by human hands of different lab technicians, which have various open force, speed or directions when performing the tests. Even though when tests are performed by the same technician, it is still hard for the lab technician to perform every test in the same way, which will affect the accuracy of the test results.

Thus, due to the huge human variables in current Coopervision's test method, the test results are not accurate enough to reflect the packaging perforation quality, which will have a negative impact on packaging material procurement and the overall quality of packaging system. Actually, the test results vary in a wide range which causes packaging material issues. For example, one technician might find it is hard to open a certain packaging perforation design and have lots of failure when performing the tests. While another technician might find it is easy to open the packaging perforation design without any issues. Based on the test result of the first technician, the packaging department will end up asking the supplier to make the perforation design easier to open. But based on the test result of the second technician, no change will be required from the supplier. In fact, it's two different test results from the same test samples. In this case, the conflict results will make the supplier go back and forth on packaging perforation design and there is no clear standard nor a test method for the supplier to comply. Thus, the miscommunication between Coopervision and its supplier may impact the stability of overall packaging system quality.

Since it is not easy to measure the quality of packaging perforations by using current 'human hand tests' due to the impact of human variables when testing, there is necessity to establish a test method and standard to quantify packaging perforation quality accurately, which ensures that the qualified packaging perforation could be torn along the perforated lines easily by variant customers as well as withstand the damage of packaging assembly line, handling and product distribution. In order to better qualify the packaging perforations, a new test method should be developed. This ideal test method will not only simulate human hands tearing process perfectly, but also repeat tests in the same method every time with human variables eliminated. Thus, a mechanical test method is highly recommended to replace current 'human hand tests' for qualifying packaging perforations because of the needs of eliminating human variables during the current tests.

1.3. Study Objective

In order to achieve the objective of this thesis, a test method needs to be developed with the usage of test equipment like tensile tester or other test equipment if necessary. Before any test method or mechanical equipment is being developed, a complete knowledge and understanding of human hand opening pattern is required since the test method is developed based on human hand opening pattern. The new test method will try to simulate human hand opening pattern as close as possible with eliminated human variations. After human hand opening pattern is studied and a test method is established, a validation will be conducted to validate the test method.

This paper is to investigate and develop a test method to qualify packaging perforations. The test method and standard will be created for a specific packaging perforations design at this time, but it will be applied to all packaging perforations designs within Coopervision's product families in the future.

2. Review of the Literature

In packaging industry, packaging perforations design is a critical feature to improve user experience because of its ease of opening. Nowadays, although packaging perforations are widely used and can be found everywhere, there are few studies existing on the topic of paperboard perforations quality test methodology.

American Society for Testing and Materials (ASTM) used to have a test method called ASTM D4987-99(2008) Standard Test Method for Tensile Breaking Strength of Perforations in One-Part Continuous Forms Paper, which is associated with perforation testing. Test samples are taken differently for folded perforations and unfolded perforations. Test specimens are then tightly clamped in the lower and upper jaw in tensile tester and the load is applied. The nearest three data points of each individual breaking load are recorded to calculate the average breaking strength of the specimens of each perforation. This test method was withdrawn in August 2010 because there has been no interest in properties based specifications for paper for over a decade. Since the test specimen is a 1 in strip cut from the original package, this test method is more focused on testing the paper properties than testing the packaging perforations in a whole. Although this test method is a good start for perforations tests, it is still too simple to replace the human hand testing. A more complex test method is required to simulate human hand opening process.

Some studies have been done to investigate packaging perforations by end user tests. Composed by the Lund University in Sweden, the study tried to find out the best plastic cap and the best perforations among the Swedish market by conducting usability tests. After products with different caps and cartons with different perforations were chosen, 10 people were invited to participate in an end user study. The results showed that a majority of participants agreed with the same easiest bottle cap and carton perforation design to open. In this study, some strength tests were performed on carton perforations by using an artificial thumb and a tool with two hooks on both sides to measure the required strength to open each package perforations. The artificial thumb was used to connect packaging perforation with tool's one side hook and when people pulled the other side of the hook, the pull strength could be read. It was found that the easiest package perforation to open actually needed the less pull strength. The package perforations used in this study was used for milk or beverage, which had more thick materials and open resistance compared to 30-Pack package design. The test method used in this study could not be considered as a mechanical test method since the test was performed by human hands and had a lot of variables. The author had experienced a very high standard deviation that the last two test groups could not be analyzed and were considered useless. In conclusion, this study used usability test to find out the best package designs and used some strength test to confirm the results. However, due to the high standard deviation when using this tool for strength test, another test instrument should be used for more reliable results.

Figure 2.1 Tool used during the strength test

While not many packaging perforations studies were found, several studies have been done to investigate another similar packaging design – packaging jar opening. The University of Sheffield developed a torque-measuring device, which was used to understand the ability of aged consumers to solve packaging open ability issues. The results indicated that the force can be applied to a package was mainly depended on age and physical condition of a human and the package itself. The authors believed that in order to design inclusively, it was important to fully understand the ability of the target users and the forces required to open the packaging, specific tests must be done to make sure that the highest possible percentage of consumers would be able to open a product. However, the torque-measuring device was only a device for recording the input, but not a testing device which was able to test a packaging jar to see if the jar was easy to open. The 30-Pack was currently tested by human hands to make sure the packaging perforation was easy to tear. But the test results were hard to compare and analyze due to the human variables during the tests.

A further study was performed by National Cheng Kung University to analyze the jar opening movement. 42 people participated in this study and performed the jar opening movement using a custom instrument with three opening postures. The results showed that the resultant force and overall torque of the right hand significantly increased from the vertical to the off-table posture. This study showed that different opening postures, left/right hand will impact the jar opening movement. These factors should be considered when studying the 30-Pack packaging perforations design.

In conclusion, the package perforations open ability was mainly depend on human factors and the package itself. When a package perforation was tested by a human hand, the results are not considered reliable since there were a lot of human variables. A mechanical test method was desired since it could eliminate human variables to provide a consistent test each. Before a mechanical test method is developed, it is important to fully understand the ability of the target users and the possible ways that used to open packaging perforation. In order to gain a better understanding of how end users open the packaging, it is necessary to conduct some usability tests. After a mechanical test method is developed, the results of usability tests could be used to validate the mechanical test method.

3. Materials and Testing Method

3.1. Sample Preparation

Test samples are printed and folded cartons with 30 packaged contact lenses inside. Test samples are called ‘30-Pack’ and are finished goods provided by Coopervision. In this paper, only 30-Pack carton design will be used and studied.

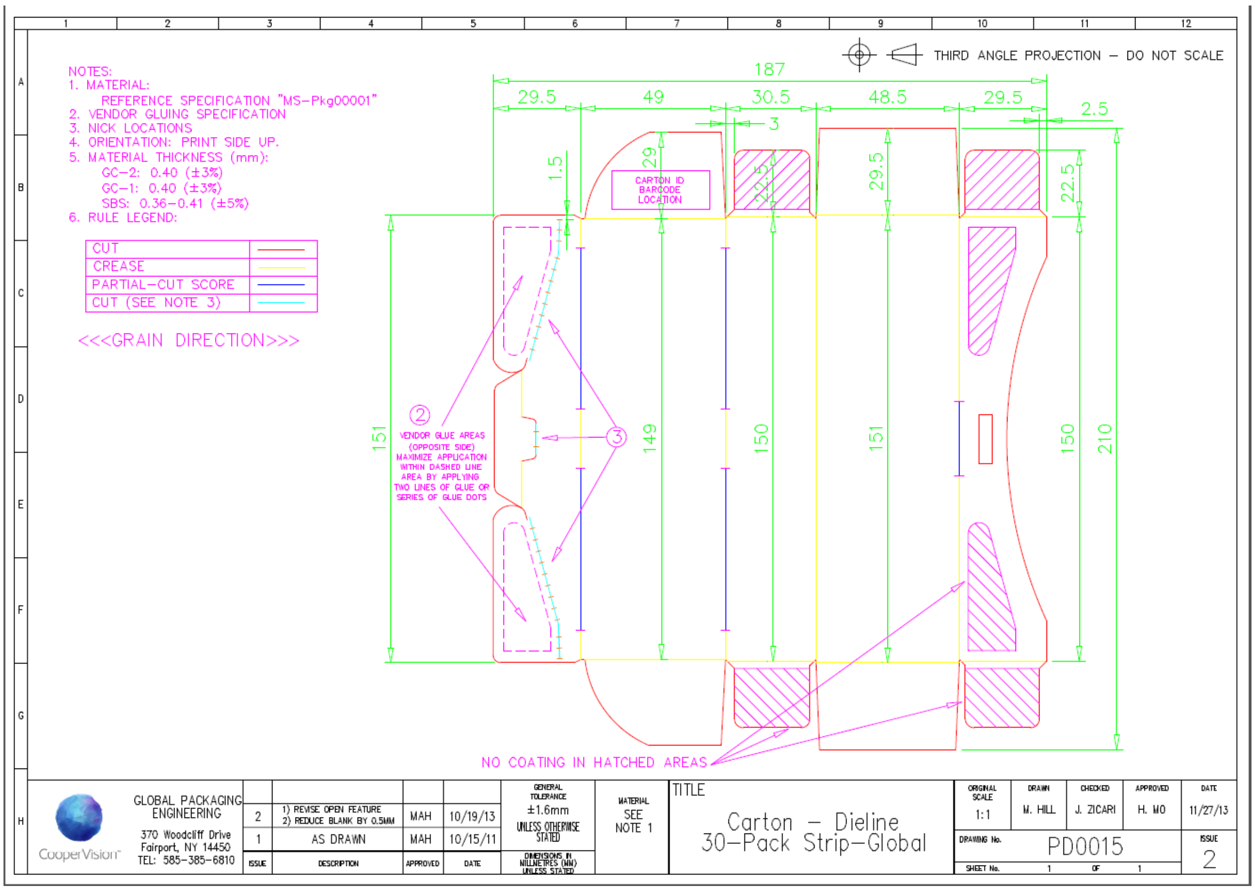


Figure 3.1 30-Pack Carton Die line

3.2. Sample Materials

Below is the paperboard material information for 30-Pack carton:

Fully coated, BCTMP, GC-1 paperboard (coated white back)

Material Layer Structure

Coated Top Layer - Double coating

Top Material Layer - Bleached chemical pulp

Middle Material Layer - Bleached chemi-thermo-mechanical pulp

Bottom Material Layer - Bleached chemical pulp

Coated Bottom Layer - Blade coating

3.3. Test Method

The purpose of this paper is to eliminate the impact of human variables when test samples are performed by 'human hand test method'. In order to achieve this goal, a new test method should be developed with as less human variations as possible. The development of this test method will be 3 steps as followings:

- **Find end users' opening patterns**

Since end users in different age and gender group will have different open methods / strength / speed, use left hand or right hand, tear in various directions, etc. The first step of this study was to conduct a survey to find out how end users will open this packaging perforations. A certain number of participants will be invited to open the 30-Pack samples. Participants' characteristics will be based on the age and gender group and a camera will be used to record all testing processes. After all participants' tests are recorded, an analysis will be made to compare the similarity and difference between all opening patterns performed by each participant.

- **Analyze end users' typical opening pattern**

Based on the result of the previous survey, an opening pattern that was used by most of participants will be carried out as the typical opening pattern. The typical opening pattern is an opening process which represents how most end users will open the packaging perforations. Thus, a complete analysis of the typical opening pattern is very important since the new test method will try to simulate the typical opening pattern as much as possible. The typical opening pattern will be analyzed by performing an experiment and the new test method will be developed based on the results of analysis.

- **Develop and validate new test method**

Once the typical opening pattern is analyzed, a mechanical test method will be developed based on the analysis result to mimic the typical opening pattern as similar as possible. In order to establish and implement this mechanical test method, the utilization of test equipment like Instron tensile tester or other test apparatus is required if necessary.

After the new test method and equipment is developed, a validation of this test method is required, which will be conducted by testing a certain number of 30-Pack samples under different test conditions. Test results will be analyzed and compared to typical opening pattern to see if the mechanical test method were able to simulate the typical opening pattern and could be used in the future to replace the current human hand test method.

4. Results and Discussion

4.1. Find End Users' Opening Pattern

A survey was conducted to have a better understanding of how end users will open the packaging perforations. Under this survey, potential end users were randomly selected and asked to open a 30-Pack sample by themselves and in their own ways. During this survey, a digital camera was used to record each opening process, the age and gender information of each participant was documented. After the opening process was performed by each participant, the use of left / right hand, opening pattern and damage profile were evaluated.

Table 4.1 Summary of end users survey

Participant	Gender	Age	Hand	Opening Pattern
1	F	23	R	Hold the box with left hand, use right hand to grab the tab, lift tab and open the box. The position of carton in hand is different than others
2	F	30	R	Hold the box with left hand, use right hand to grab the tab, lift tab and open the box , insert right hand fingers into the box (under the panel) to tear unopened perforations and finish opening process.
3	M	24	R	Hold the box with left hand, use right hand to grab the tab, lift tab and open the box slowly. Then use right hand to open unopened perforations in left and right side
4	M	24	L	*Hold the box with right hand, insert left hand fingers into the box (under the panel) to tear left side perforations, insert right hand fingers into the box (under the panel) to tear right side perforations and open the box*
5	F	23	R	*Hold the box with left hand, insert right hand fingers into the box (under the panel) from right to left side to tear perforations quickly and open the box*
6	M	28	R	Hold the box with left hand, use right hand to grab the tab, lift tab and open the box
7	F	25	R	Hold the box with left hand, use right hand to grab the panel, lift panel and open the box
8	M	25	L	Hold the box with right hand, use left hand to grab the tab, lift tab panel and open the box
9	M	24	R	Hold the box with left hand, use right hand to grab the panel, lift panel and open the box

10	M	30	R	Hold the box with left hand, use right hand to grab the tab, lift tab and open the box
11	M	20	R	Hold the box with left hand, use right hand to grab the tab, lift tab and open the box
12	F	23	R	Hold the box with left hand, use right hand to grab the tab, lift tab and open the box
13	M	21	R	Hold the box with left hand, use right hand to grab the tab, lift tab and open the box a little bit, then grab the panel and open the box
14	M	27	R	Hold the box with left hand, use right hand to grab the tab, lift tab and open the box
15	M	25	R	*Hold the box with left hand, insert right hand fingers into the box (under the panel) to tear perforations and open the box*
16	M	25	R	Hold the box with left hand, use right hand to grab the tab, lift tab and open the box slowly, then use right hand to open unopened perforations in left and right side
17	M	29	L	Hold the box with right hand, use left hand to grab the tab, lift tab and open the box

From the above chart, a total number of 17 end users were selected to perform the tests. The participants were consisted of 12 males and 5 females. The age of the participants were range from 21 to 30. Only 3 participants used left hand while the rest of participants all used right hand.

Each participant's opening pattern was evaluated by reviewing recorded videos. According to the above chart, 82.3% of participants' opening patterns were very similar: hold the box with one hand, use another hand to grab the tab, lift tab and open the box. Thus, this opening pattern could be defined as the typical opening pattern, although some participants had some slight difference, like using left hand to open the box, grab the panel part instead of tab and opening speed difference. Compared to the typical opening pattern, the rest of participants had a different opening pattern: Instead of grabbing and lifting the tab, they tended to insert their fingers into the box and put them underneath the panel, then tear perforations by going left or right and eventually open the box.

Figure 4.1 Typical opening pattern

Figure 4.2 Insert to open opening pattern

- **Damage profile**

Table 4.2 Summary of damage profile

Sample Number	**Defect "Start'' and "End'' Location**	**Location of Defect**	**Type of Defect**	**Picture**
Sample 6	Delamination started to happen at the left side perforation line when participant was lifting the panel, ended at upper carton line	Left side near the corner	Unopened perforations and delamination	
Sample 11	Delamination started to happen at the left side perforation line when participant was lifting the panel, ended at upper carton line	Left side near the corner	Unopened perforations and delamination	

Sample 12	Delamination started to happen at the left side perforation line when participant was lifting the panel, ended at upper carton line	Left side near the corner	Unopened perforations and delamination	

During the survey, 3 of 17 test samples were found with defects, which were test sample 6, 11, 12. These three samples had very similar defects since the location of defects and the type of defects were the same. Both 3 samples had unopened perforations and delamination in the left side perforations and the locations of defects were very close to the left side corner of the carton. For these 3 samples, the "start'' and "end'' positions of defects were also the same, they all started to happen at the left perforations line. When people continued to lift the tab, the paper board started to delaminate until the front panel was lifted up. The end positon was the upper carton line. Although test sample 6, 11, 12 were performed by different participants, it was found that the damage profiles of 3 test samples were very similar with respect to type, location and start & end positions of defects.

- **Conclusion**

This survey concluded that when opening 30-Pack packaging perforations, most people use the same opening pattern: hold the box with one hand, use another hand to grab the tab, lift tab and open the box. Thus, the new test method could be developed based on this typical opening pattern.

4.2 Analyze End Users' Typical Opening Pattern

The previous survey found that when opening a 30-pack package, most people tend to use the same opening pattern: "hold the box with one hand, use another hand to grab the tab, lift tab and open the box". Before any test instrument is selected or made to simulate this open process, a complete analysis of the open process is essential. An experiment was conducted to further analyze the typical opening pattern.

In this experiment, 5 participants were asked to open 25 30-Pack samples using the typical opening pattern found in the survey (5 30-Pack samples per person). 30-Pack samples were placed on a plat table with perforations side up. All appraisers were asked to use the same typical opening pattern: Hold the box with one hand, use another hand to grab the tab, lift tab and open the box. A high speed camera was used to record all 25 open processes at 60 frames per second. The camera height and focus were properly set up so that each test could be recorded in the same condition, which allows for further comparison and analysis.

- **Test Equipment**

Figure 4.3 Camera for test: Canon’s 550D

Figure 4.4 Sunpak PlatinumPlus 5858D's 58" tripod

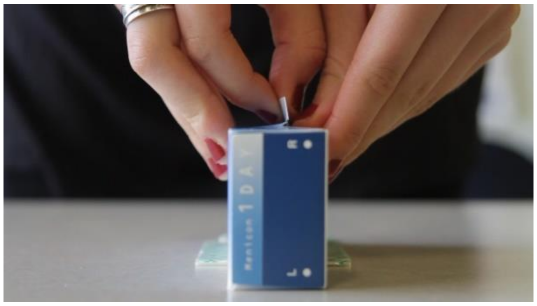
Figure 4.5 Experiment Set Up

- **Test and Data Analysis**

Table 4.3 Summary of typical opening pattern analysis experiment

Participant	Gender	Age	Hand	Label
P1	F	25	R	P1-1, P1-2, P1-3, P1-4, P1-5
P2	M	27	R	P2-1, P2-2, P2-3, P2-4, P2-5
P3	F	23	R	P3-1, P3-2, P3-3, P3-4, P3-5
P4	M	29	R	P4-1, P4-2, P4-3, P4-4, P4-5
P5	M	25	R	P5-1, P5-2, P5-3, P5-4, P5-5

All 25 opening processes were recorded and labeled as P1-1, P1-2, P1-3, P1-4, and P1-5…P5-5. A timeline-based video editing software application called Adobe Premiere Pro was used to edit original test videos. Each video was edited by Adobe Premiere Pro to only contain opening process from the start position to the end position. The start position is the moment when the tab is being lifted and started to move while the end position is the moment when all perforations were torn apart.



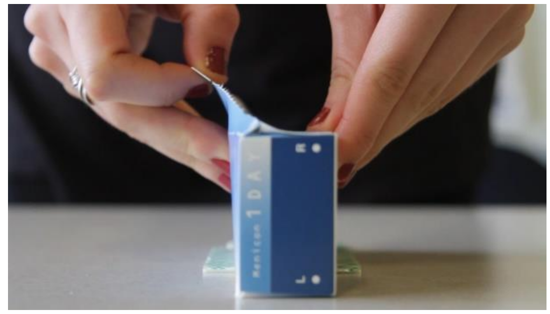


Figure 4.6 Start position Figure 4.7 End position

After all test videos were edited, frame pictures of each test video were also exported. For example, if an opening process from the start position to the end position lasted 1 second, 60 frame pictures will be exported since the high speed camera's frame per second rate is 60 frames per sec.

From the exported frame pictures, it was found that the position of tab point in each frame picture was moving during the opening process, which could be used for calculating the trail of the opening process. The tab point was actually a crease line between the front panel and the tab. This crease line became a point when it was observed from the side. Thus it is feasible to capture the tab point position in each frame picture from the start position to the end positon and calculate the trail of the opening process in Matlab. A programming code was developed to achieve this calculation in Matlab (see Appendix A).

Take the first test as an example, the first test was performed by participant 1 and the test video was labeled as P1-1. P1-1 test video was first edited in Adobe Premiere Pro to remove the redundant part and the opening process time was 1.95s, which equaled to 117 frame pictures (60 frames per second). Then, all 117 frame pictures were exported by Adobe Premiere Pro, which represented the opening process from the start position to the end position. According to the

Matlab programming code, all frame pictures had to be imported into Matlab for image processing. The first frame picture was read and displayed by Matlab and the position of tab point could be located by clicking the mouse on the screen. Once the position of tab point was located, X-coordinate and Y-coordinate values were both recorded since Matlab could load each frame picture in defaulted X-Y axes. After the analysis of the first frame picture was completed, the 3rd, 5th, 7th …frame picture was read, displayed and processed in the same way until the last frame picture. It is not necessary to read, display and process every frame picture from one test since there was no much tab point position difference between adjacent frame pictures when the total opening time is relatively long. For test sample P1-1, tab point position was read, displayed and processed every two frames.

After all frame pictures were processed, the first frame picture's X-coordinate and Y-coordinate values were set as origin, which was Zero, Zero (0, 0). And the rest of frame pictures' X-coordinate and Y-coordinate values were converted based on the first frame picture's X-coordinate and Y-coordinate values. X-coordinate and Y-coordinate values could be converted again from Matlab's Pixel values to real displacement in mm.

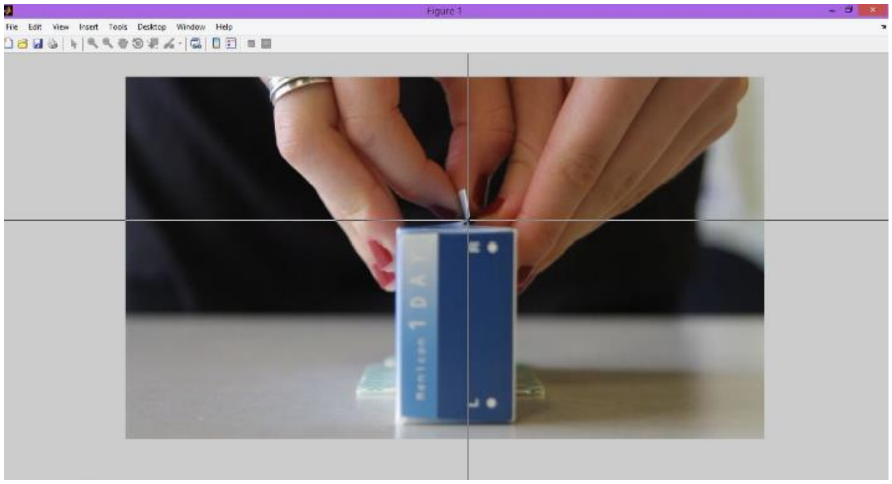


Figure 4.8 Locate tab point position in Matlab at the start position

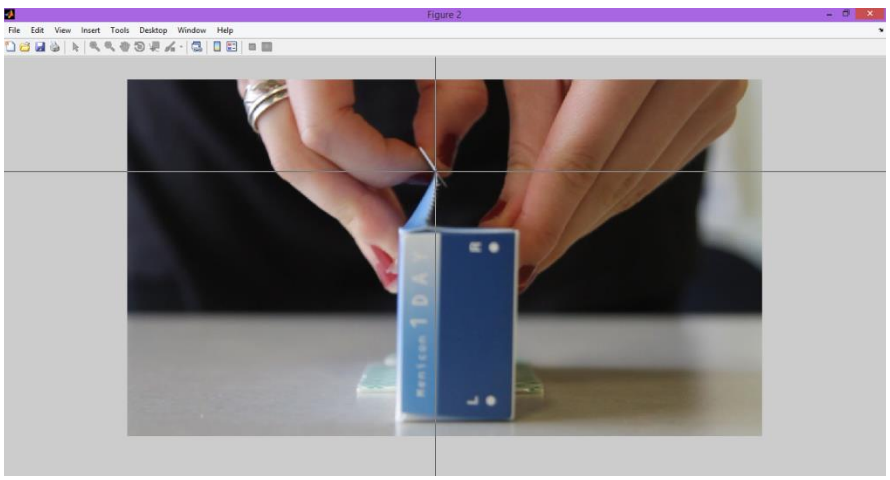


Figure 4.9 Locate tab point position in Matlab during the opening process

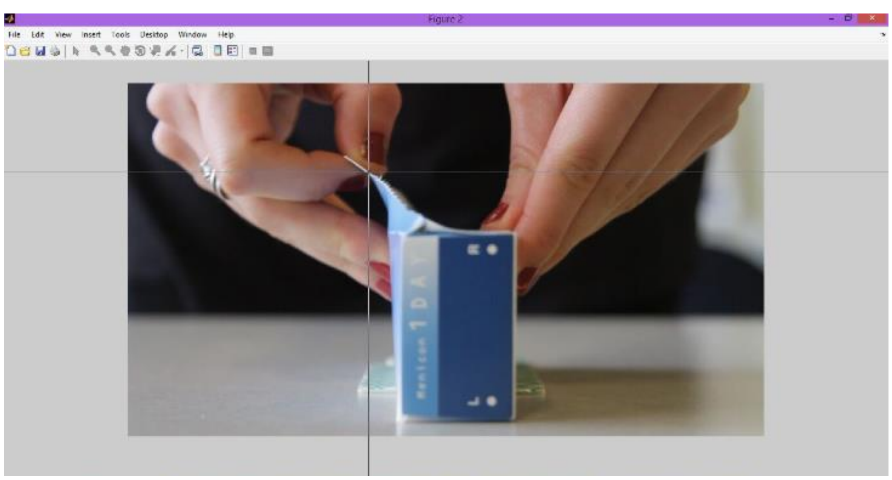


Figure 4.10 Locate tab point position in Matlab at the end position

By gathering the X-coordinate and Y-coordinate values of each processed frame picture, we were able to put all X-coordinate and Y-coordinate values together and calculate the trail. The chart below shows the trail of tab point position movement during P1-1 test sample opening process from the start position to the end position.

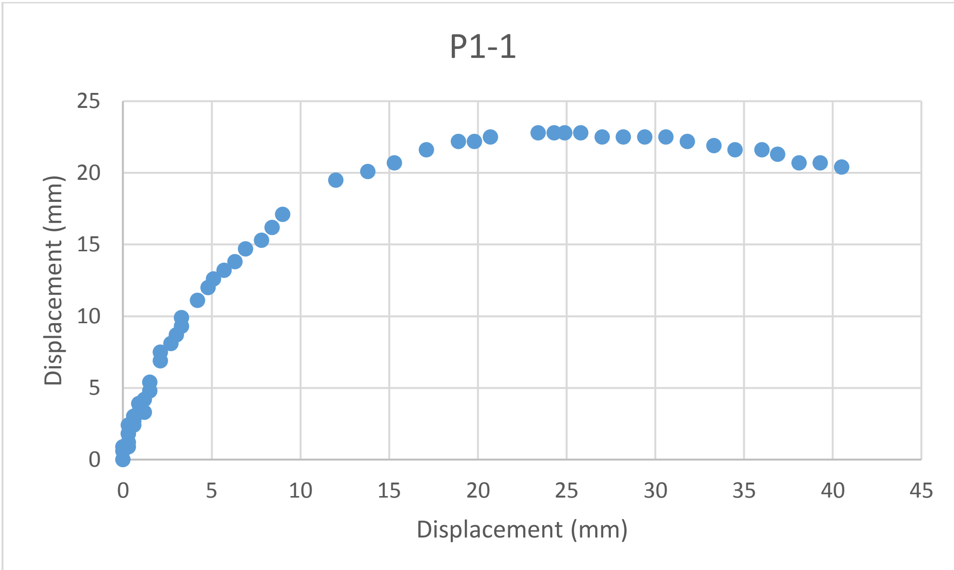


Figure 4.11 Trail of tab point position movement for test sample P1-1

The trail of tab point position movement was consisted of horizontal movement and vertical moment. In this study, horizontal direction was named X direction and vertical direction was named Y direction. The chart below still shows the trail of tab point position movement during P1-1 test sample opening process from the start position to the end position. The opening time was added to the chart and the movement was separated as horizontal movement and vertical moment, which was called X-Displacement and Y-Displacement.

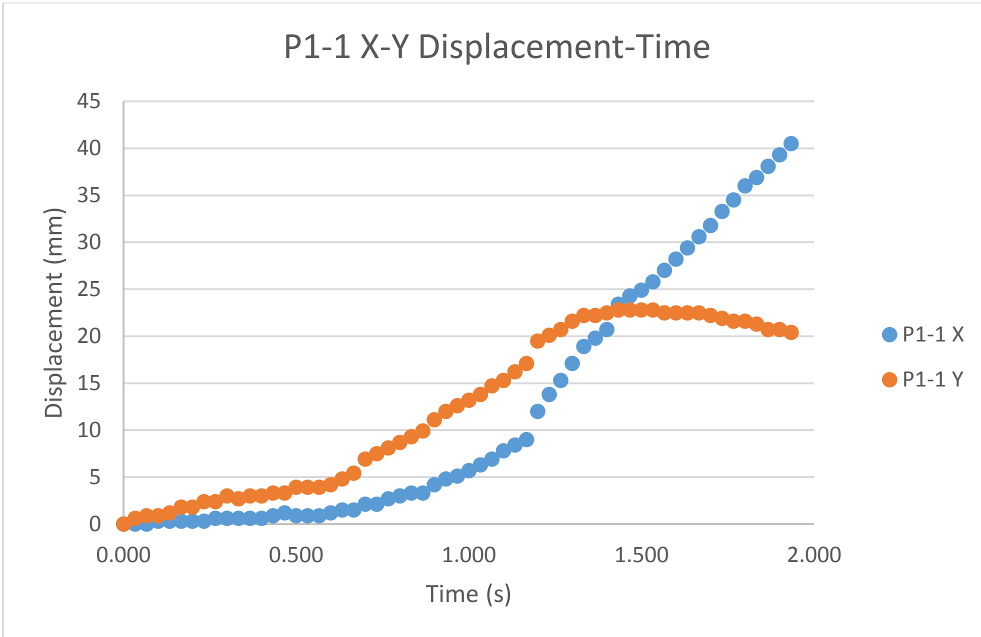


Figure 4.12 P1-1 X-Y Displacement-Time Curve

The P1-1 X-Y Displacement-Time curve could also be separated into two charts: P1-1 X Displacement-Time curve and P1-1 Y Displacement-Time curve.

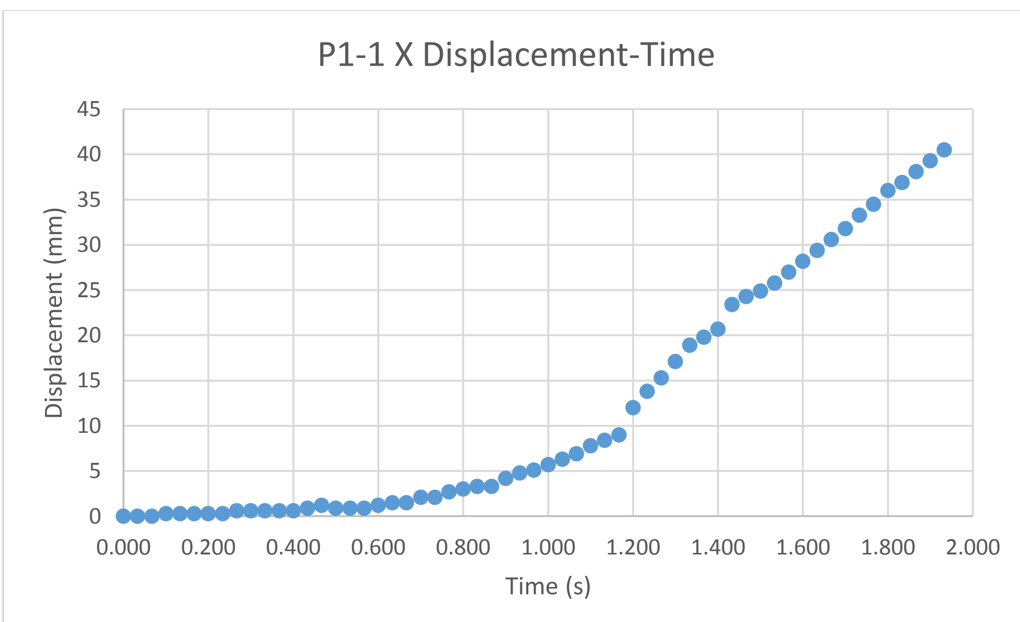


Figure 4.13 P1-1 X Displacement-Time Curve

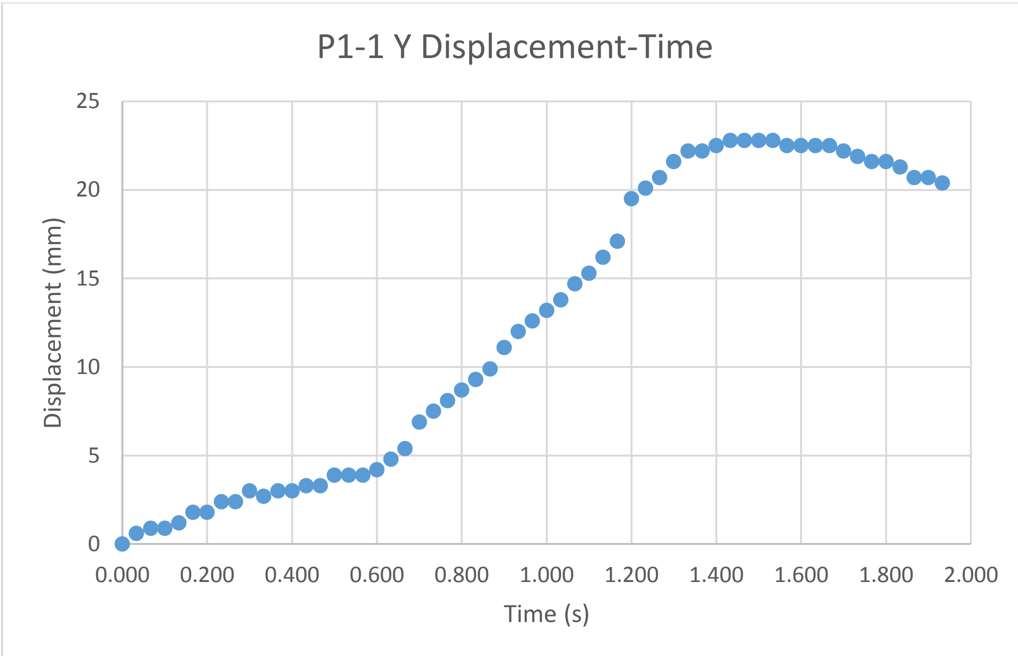


Figure 4.14 P1-1 Y Displacement-Time Curve

The rest 24 test samples were processed and analyzed in the same way as P1-1, all 25 test samples' opening time, final displacement in horizontal direction (X-Displacement) and final displacement in vertical direction (Y-Displacement) data were recorded in the table below.

Table 4.4 P1, P2, P3, P4, P5 - Opening Time, Final X-Displacement and Y-Displacement

P1	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**	**P2**	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**
P1-1	1.933	40.50	20.40	**P2-1**	1.233	37.50	21.60
P1-2	1.050	43.80	20.10	**P2-2**	1.100	34.20	19.20
P1-3	1.400	41.70	20.40	**P2-3**	1.200	32.40	20.40
P1-4	1.050	38.40	20.40	**P2-4**	1.233	33.00	19.80
P1-5	1.433	37.20	18.60	**P2-5**	1.633	36.30	19.80
Avg.	*1.373*	*40.32*	*19.98*	**Avg.**	*1.280*	*34.68*	*20.16*
STD	*0.363*	*2.62*	*0.78*	**STD**	*0.205*	*2.17*	*0.91*
P3	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**	**P4**	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**
P3-1	0.617	52.80	20.10	**P4-1**	0.433	48.60	25.50
P3-2	0.500	43.20	18.00	**P4-2**	0.383	50.70	22.80
P3-3	0.533	39.30	20.70	**P4-3**	0.433	47.10	24.00
P3-4	0.400	42.90	20.70	**P4-4**	0.433	43.50	23.10
P3-5	0.400	36.00	21.00	**P4-5**	0.350	51.90	19.50
Avg.	*0.490*	*42.84*	*20.10*	**Avg.**	*0.406*	*48.36*	*22.98*
STD	*0.092*	*6.30*	*1.22*	**STD**	*0.038*	*3.29*	*2.21*
P5	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**	**P1,P2, P3,P4, P5**	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**
P5-1	0.983	49.80	19.80				
P5-2	1.117	35.10	20.10	**Overall Avg.**	*0.938*	*41.30*	*20.66*
P5-3	0.583	41.70	18.90				
P5-4	1.867	37.50	19.50				
P5-5	1.150	37.50	22.20	**Overall STD**	*0.489*	*6.03*	*1.72*
Avg.	*1.140*	*40.32*	*20.10*				
STD	*0.465*	*5.81*	*1.25*				

According to the table above, it is found that even 5 participants were asked to use the same typical opening pattern to open packages, the test results between each participant were still different. The overall average of opening time was 0.938s with a standard deviation of 0.489s, the overall average of X-Displacement was 41.30mm with a deviation of 6.03mm and the overall average of Y-Displacement was 20.66mm with a standard deviation of 1.72mm.

For the opening time, P3 and P4 only used an average opening time of 0.490s and 0.406s while P1, P 2 and P 5 used an average opening time of 1.373s, 1.280s and 1.140s. P2, P3, P4 had a relatively smaller standard deviation for opening time, which indicated that the opening process for P2, P3, P4 were more consistent than P1 and P5. P1's opening time ranged from 1.050s to 1.933s with a standard deviation of 0.363s while P5's opening time ranged from 0.583s to 1.867s with a standard deviation of 0.465s. The shortest opening time was 0.350s (P4-5) and the longest opening time was 1.933s (P1-1). The reason for these opening time differences was due to the various opening speed used by different participants.

For final displacement in horizontal direction (X-Displacement), the X-Displacement of P1, P2, P3, P4, and P5 were relatively close compared to opening time. P1, P3, P5 had similar average X-Displacement which were 40.32mm, 42.84mm and 40.32mm while P2 and P4 had average X-Displacement of 34.68mm and 48.36mm. P1, P2, P4 had a smaller standard deviation than P3 and P5. The shortest X-Displacement was 32.4mm (P2-3) and the longest X-Displacement was 52.8mm (P3-1).

For final displacement in vertical direction (Y-Displacement), the Y-Displacement of P1, P2, P3, P4, and P5 were almost the same since they were all close to each other and the overall standard deviation value was small (1.72mm. The standard deviation value in each subgroup were also small. The shortest Y-Displacement was 18.00mm (P3-2) and the longest X-Displacement was 24.00mm (P4-3). Thus, it was found that the variations between each participant for Y-Displacement is relatively small, compared to opening time and X-Displacement.

Table 4.5 P1, P2, P3, P4, P5 Average Speed in Vertical Direction (Y)

P1	**Y-Speed (mm/s)**	**P2**	**Y-Speed (mm/s)**	**P3**	**Y-Speed (mm/s)**
P1-1	10.55	**P2-1**	17.52	**P3-1**	32.58
P1-2	19.14	**P2-2**	17.45	**P3-2**	36.00
P1-3	14.57	**P2-3**	17.00	**P3-3**	38.84
P1-4	19.43	**P2-4**	16.06	**P3-4**	51.75
P1-5	12.98	**P2-5**	12.12	**P3-5**	52.50
Avg.	*15.33*	**Avg.**	*16.03*	**Avg.**	*42.33*
P4	**Y-Speed (mm/s)**	**P5**	**Y-Speed (mm/s)**	**P1,P2,P3,P4,P5**	**Y-Speed (mm/s)**
P4-1	58.89	**P5-1**	20.14	**Overall Avg.**	*30.07*
P4-2	59.53	**P5-2**	17.99		
P4-3	55.43	**P5-3**	32.42		
P4-4	53.35	**P5-4**	10.44		
P4-5	55.71	**P5-5**	19.30		
Avg.	*56.58*	**Avg.**	*20.06*		

From the typical opening pattern analysis, it is found that the movement of the opening process could be divided into movement of horizontal (X) and vertical (Y) directions. Average speed of each participant in vertical direction could be calculated based on opening time and final displacement in vertical direction. Average speed of all 25 participants in vertical direction were calculated in chart above. The average speed in vertical direction could range from 10.55 mm/s to 59.53 mm/s with an overall average speed of 30.07mm/s.

All 25 test samples' X Displacement-Time curves were put together in one chart as below.

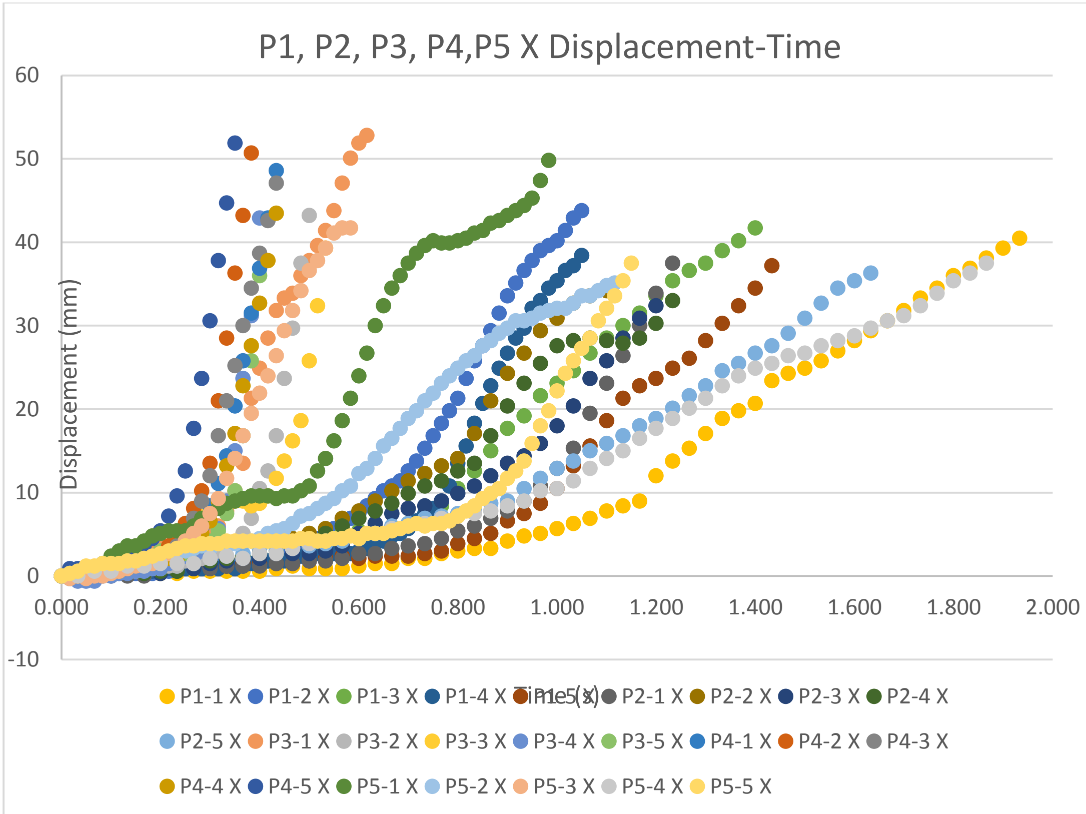


Figure 4.15 P1, P2, P3, P4,P5 X Displacement-Time Curve

The 25 test samples could be simplified as chart below, which only contained 4 curves: P1-1X, P4-5X, P2-3X, P3-1X. These 4 curves represented the longest opening time, shortest opening time, shortest final displacement and longest final displacement in horizontal direction respectively. The simplified chart below is a summary of P1, P2, P3, P4, P5 X Displacement-Time curve (Horizontal Direction).

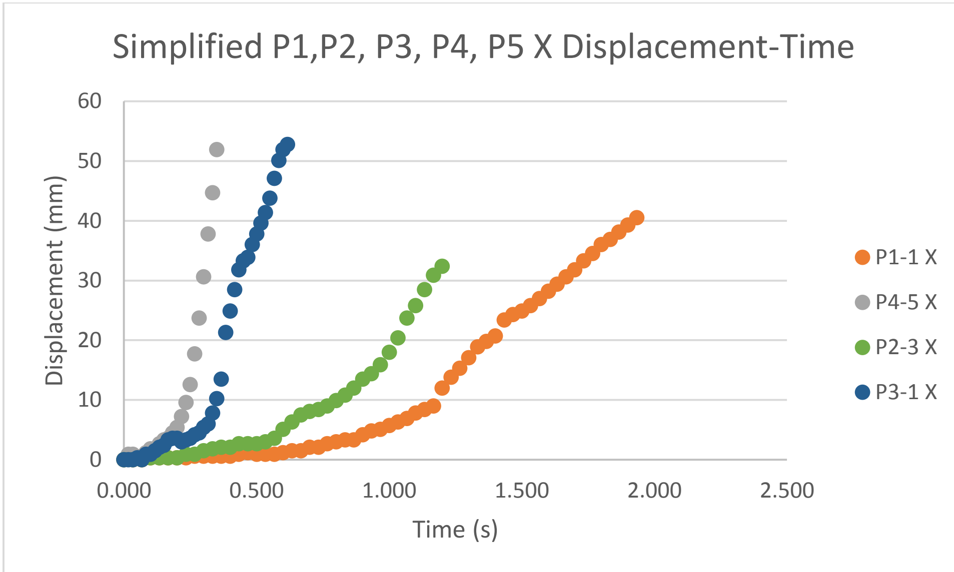


Figure 4.16 Simplified P1, P2, P3, P4,P5 X Displacement-Time Curve

All 25 test samples' Y Displacement-Time curves were put together in one chart as below.

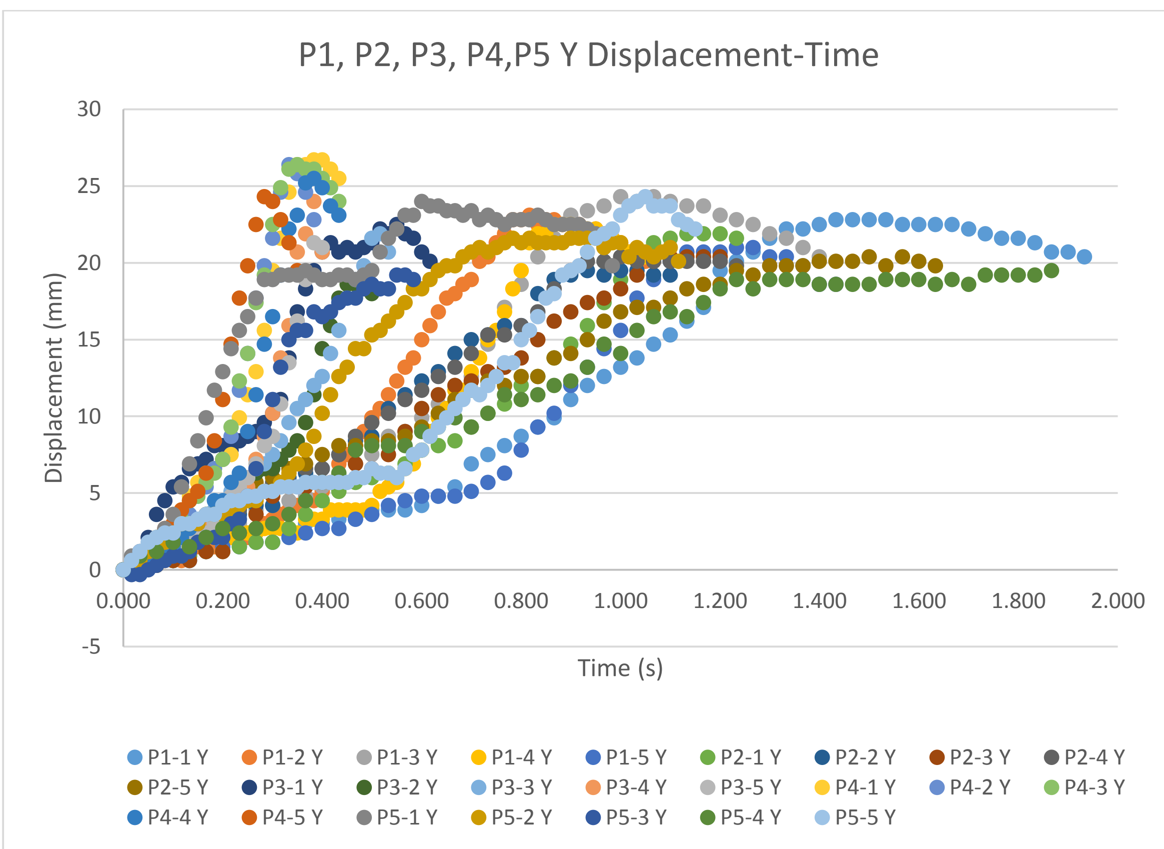


Figure 4.17 P1, P2, P3, P4,P5 Y Displacement-Time Curve

The 25 test samples could be simplified as chart below, which only contained 4 curves: P1-1Y, P4-5Y, P3-2Y, P4-1X. These 4 curves represented the longest opening time, shortest opening time, shortest final displacement and longest final displacement in vertical direction respectively. The simplified chart below is a summary of P1, P2, P3, P4, P5 Y Displacement-Time curve (Vertical Direction).

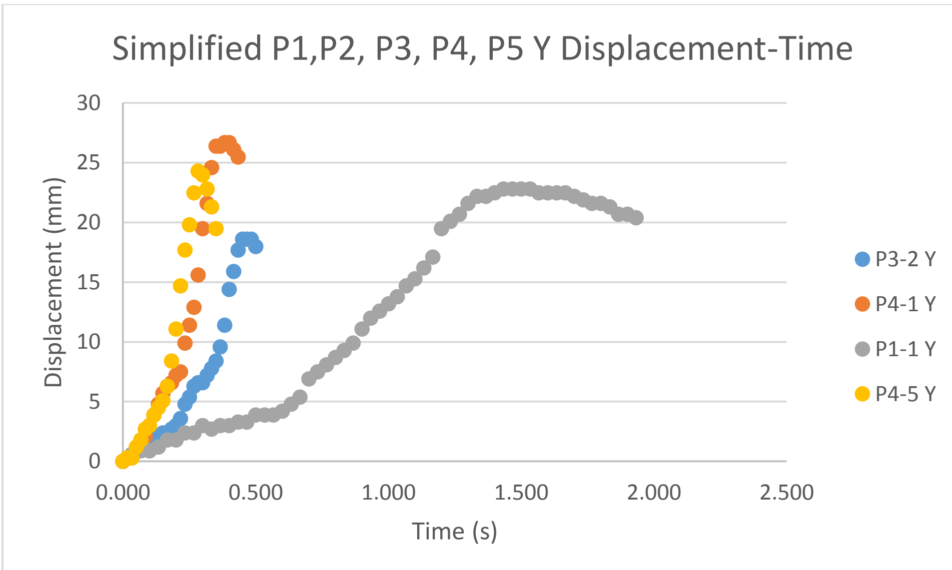


Figure 4.18 Simplified P1, P2, P3, P4,P5 Y Displacement-Time Curve

- **Damage Profile**

Table 4.6 Summary of damage profile

Sample Number	**Defect ''Start'' and ''End'' Location**	**Location of Defect**	**Type of Defect**	**Picture**
Sample P1-2	Delamination started to happen at the right side perforation line when participant was lifting the panel, ended at upper carton line	Most part of the right side	Delamination	

Sample P1-5	Delamination started to happen at the left side perforation line when participant was lifting the panel, ended at upper carton line	Left side near the corner	Unopened perforations and delamination	
Sample P2-2	Delamination started to happen at the left side perforation line when participant was lifting the panel, ended at upper carton line	Left side near the corner	Unopened perforations and delamination	
Sample P2-3	Delamination started to happen at the left side perforation line when participant was lifting the panel, ended at upper carton line	Left side near the corner	Unopened perforations and delamination	
Sample P2-4	Delamination started to happen at the left side perforation line when participant was lifting the panel, ended at upper carton line	Left side near the corner	Unopened perforations and delamination	
Sample P2-5	Delamination started to happen at the left side perforation line when participant was lifting the panel, ended at upper carton line	Left side near the corner	Unopened perforations and delamination	

6 of 25 test samples were found with defects, which were test sample P1-2, P1-5 and P2-2, P2-3, P2-4, P2-5. From the damage profile chart above, it is found that P1 had two damaged samples and P2 had 4 damaged samples while P3, P4, P5 had no damaged samples. These damaged samples had very similar defects since the location of defects and the type of defects were the same except sample P1-2. Sample P1-2 had delamination in the right and the defects of the

locations were most part of right side. The rest 5 samples all had unopened perforations and delamination in the left side perforations and the locations of defects were very close to the left corner of the carton. For sample P1-2, the ‘’start’’ and ‘’end’’ positions of defects were from the right side perforation line to upper carton line. For the rest 5 samples, the ‘’start’’ and ‘’end’’ positions of defects were almost the same, they all started to happen at the left perforations line. When people continued to lift the tab, the paper board started to delaminate until the front panel was lifted up. The end positon was the upper carton line. Although test sample P1-2 and test sample P1-5 were performed by the same participant, they still could have different defects. And it was found that the damage profiles of the rest 5 test samples were very similar with respect to type, location and start & end positions of defects. The damage profiles in typical opening pattern study were also similar to the damage profiles found in the previous survey.

- **Conclusion**

An experiment was conducted to further analyze the typical opening pattern. In this experiment, 5 participants were asked to open 25 test samples. The opening processes were recorded as videos and finally analyzed in Matlab. It was found that the opening process of typical opening pattern was consist of movements in two directions: horizontal direction movement (X) and vertical direction movement (Y). For vertical direction movement, Instron tensile tester would be an ideal equipment for opening the packaging perforations and the speed of instron could be based on the average speed in vertical direction. While Instron tensile tester could only provide a vertical direction movement, in order to simulate the human hand opening process with horizontal movement at the same time, anther instrument needed to be developed to work with Instron tensile tester to provide the horizontal movement when vertical movement was provided by Instron tensile tester.

5. Develop and Validate New Test Method

5.1. Design the Fixture

Since Instron tensile tester could only provide a vertical movement, a fixture needed to be developed to better simulate the typical opening pattern. Two initial design concepts were developed as below.

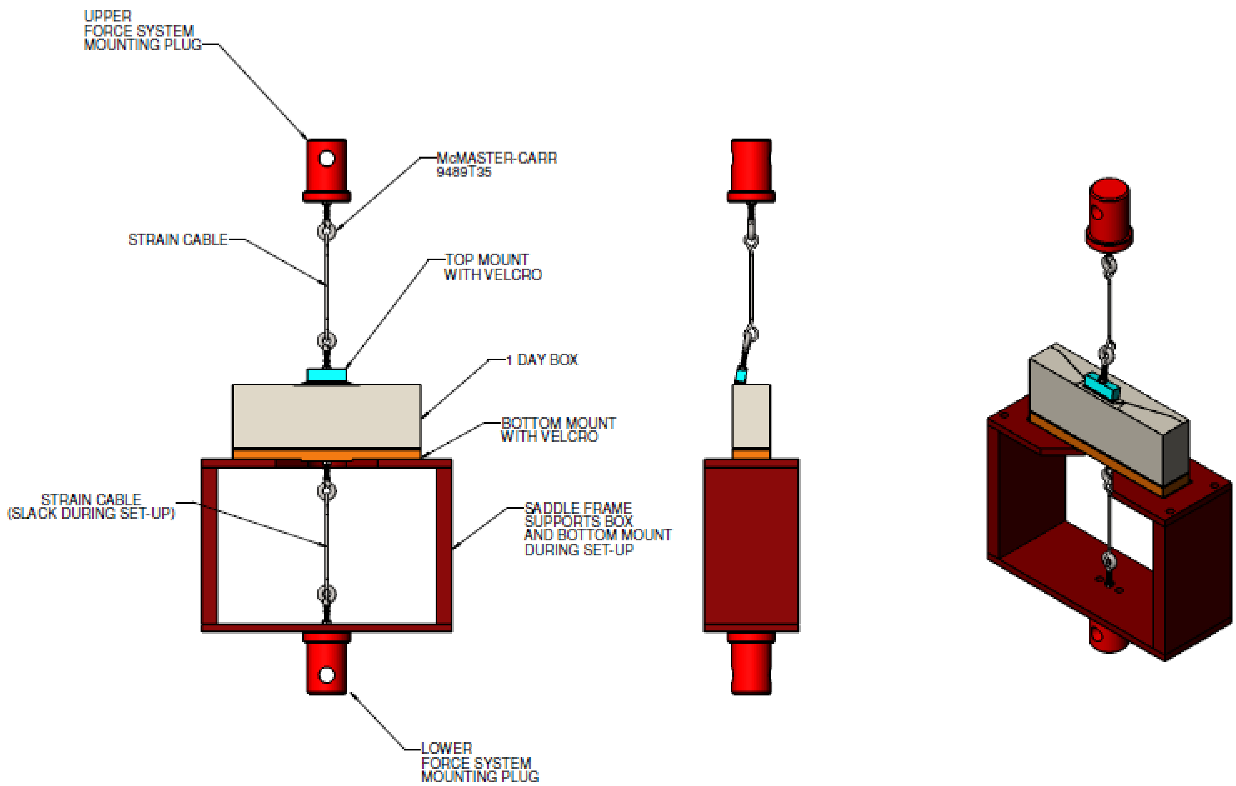


Figure 5.1 Design Concept 1

The design concept 1 had an upper force system mounting plug for connecting to the Instron tensile tester, a top mount with Velcro was connected to the upper mounting plug with a strain cable. The fixture also had a lower force system mounting plug for connecting to the Instron tensile tester, a saddle frame was built on the lower mounting plug to support box and bottom mount when bottom mount held the box with Velcro. The test sample could be loaded to the fixture by using the top and bottom mount with Velcro.

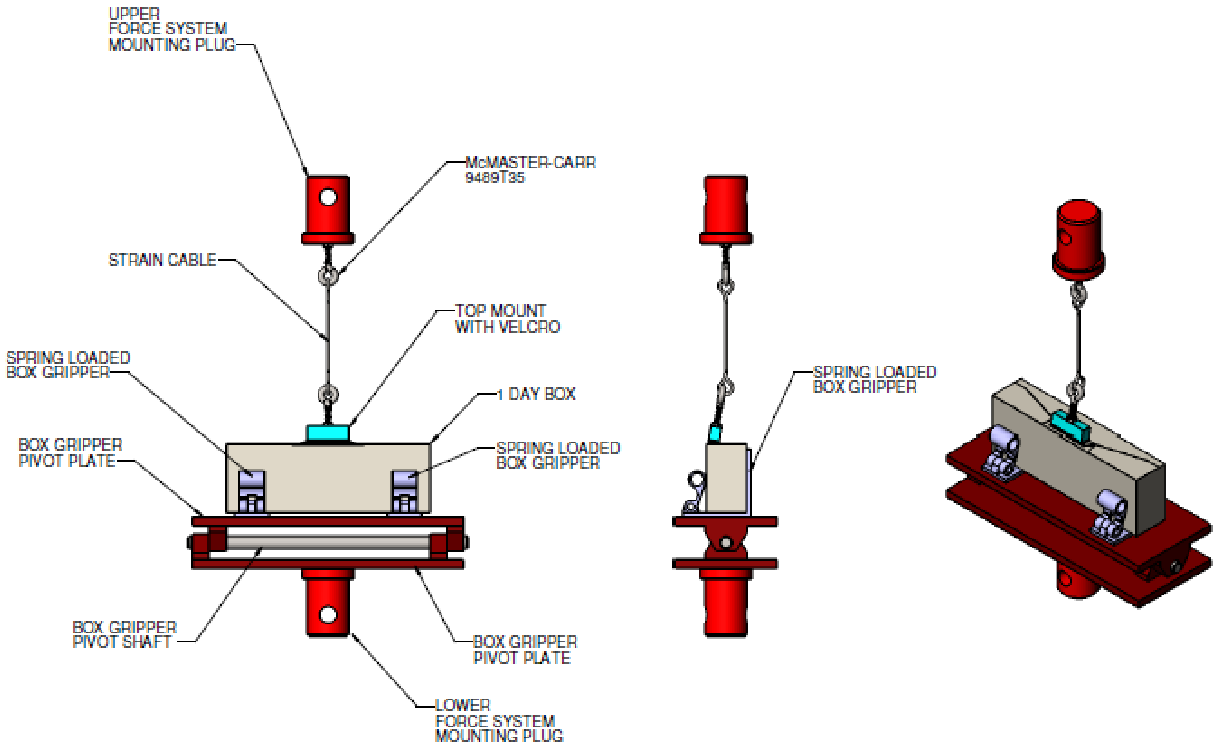


Figure 5.2 Design Concept 2

The design concept 2 had an upper force system mounting plug for connecting to the Instron tensile tester, a top mount with Velcro was connected to the upper mounting plug with a strain cable. The fixture also had a lower force system mounting plug for connecting to the Instron tensile tester, a box gripper fixture was built on the lower mounting plug. The box gripper was made of three parts: upper box gripper pivot plate, lower box gripper pivot plate and a box gripper pivot shaft connecting upper and lower pivot plates. On the Upper pivot plate, there were two spring loaded box grippers which could secure a 30-pack.

After discussion with committee, the design concept 2 was selected although design concept 2 was more expensive than design concept 1. Design concept 2 was the preferred design because it seemed to “grip” more like someone’s hand would grip the box versus Velcro. The pivoting bottom design allowed

the upper pivot plate to revolve around the pivot shaft when the tab of the box was lifted and opened by the top mount, which simulated the vertical movement of typical opening pattern. In addition, the pivoting bottom was preferred as it might open up future test options.

Figure 5.3 Final Fixture

The final fixture made was a little different from the design concept 2. First, the top mount with Velcro was not developed, instead, the box’s tab will be clamp by Instron tensile tester’s gripper directly for opening the package. Second, the two adjustable box grippers were developed to replace the secured spring load box grippers in design concept 2. The adjustable box grippers will accommodate different size of boxes in future tests.

The fixture could be self-balanced and the upper pivot plate could revolve around the pivot shaft.

When testing a loaded box, the tab part of the box will be pulled vertically by by Instron tensile tester's gripper, which allowed the upper pivot to revolve around the pivot shaft and provided a horizontal movement during the opening process. The previous study shows that the typical opening pattern) was consist of horizontal direction movement (X) and vertical direction movement (Y).Thus, the utilization of the fixture and Instron tensile tester together was a better way to simulate the process of typical opening pattern since it performed both horizontal and vertical movements.

5.2. Validate the New Test Method

The development of the new test method will be based on the utilization of the fixture and Instron tensile tester together. Before any 30-Pack sample is tested by the fixture and Instron , it is very important to test the fixture and Instron through a validation to see if the new test method really simulates the process of typical opening pattern. Thus, in order to validate the new test method, an experiment will be conducted to compare the results between the new test method and typical opening pattern.

The new test method was validated by two test methods: Test method A and Test method B. Test method B was performed by Instron tensile tester and the fixture while test method A was only performed by Inston tensile tester as the control group. The previous study showed that the typical opening pattern had an average speed in vertical direction from 10.55 mm/s to 59.53 mm/s with an overall average speed of 30.07mm/s. However, the max pull speed of Instron tensile tester was only 8.5 mm/s. So under test method B group, test samples were tested with Instron tensile tester and the fixture at three different speeds: 8.5 mm/s, 4.25mm/s, 2.125mm/s to compare the results between different speeds, 5 samples were tested per each speed. Under test method A group, test samples were tested by Instron tensile tester without the fixture at three different speeds: 8.5mm/s, 4.25mm/s, 2.125mm/s, 5 samples were tested per each speed. Test method A was considered as control group since it didn't use the fixture. The comparison between the results of test method A and test method B will indicate that if the fixture really improved the test method, when comparing to the typical opening pattern.

Table 5.1 Validation of new test method

Tensile Speed (mm/s) **Test Method**	**8.5 mm/s**	**4.25mm/s**	**2.125mm/s**
Test Method A * (without fixture)	5	5	5
Test Method B (with fixture)	5	5	5

*Note: even though test samples under test method A were performed by Instron tensile tester only (without fixture), the samples still needed to be loaded for testing. Thus, for test method A, the fixture was used for loading and securing the test samples only. During testing process, the fixture was held by hand and was not able to move.

- **Test Equipment and Pre-Test Loading**

A 30-Pack sample should be loaded properly in the fixture before any tests will be performed. From the picture below, the left and right side box grippers were adjusted to be symmetrical for the purpose of self-balancing. After a test sample was loaded on the upper pivot plate, the test sample could be secured by closing the adjustable box grippers. 2 extra strips of contact lenses were placed together with a 30-Pack sample to make sure the tab point position will be in the center of the fixture and clamped by Instron tensile tester's gripper properly. Per the picture below, the test sample was properly loaded and ready for tests.

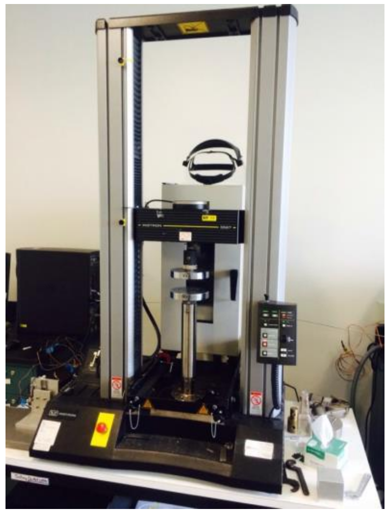


Figure 5.4 Instron Tensile Tester

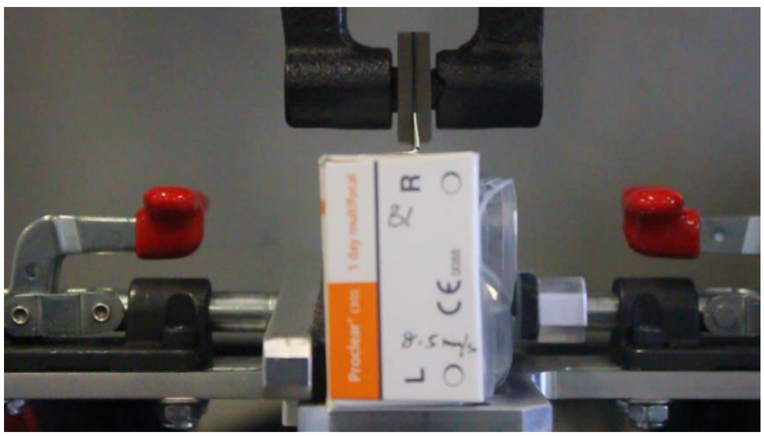


Figure 5.5 Pre-test loading

- **Test and Data Anaylsis**

Before starting to perform any tests, test samples were loaded on the fixture with the tab of box clamped by Instron tensile tester's gripper. Once the test started, Instron's gripper will begin to move up and lift the tab of box. As a result, the packaging perforations started to be torn apart until the box was fully opened. Since the box was secured in the fixture, when the tab of box was lifted by grippers, the upper pivot plate of fixture was able to revolve around the pivot shaft, which provided a movement in vertical direction. 15 samples under test method B were tested in three different tensile speed, another 15 samples under test method A were tested in the same way but without using the fixture.

All testing processes were recorded by a high speed camera and exported as videos. All 30 test samples were labeled as 8.5mm/s A1, 8.5mm/s A2…2.125mm/s A5 and 8.5mm/s B1, 8.5mm/s B2…2.125mm/s B5. A timeline-based video editing software application called Adobe Premiere Pro was used to edit the videos. Each video was edited with opening process from the start position to the end position only. Frame pictures of each video were also exported.

The analysis of these opening processes was similar to the analysis of typical opening pattern. The Matlab code used in the analysis of typical opening pattern could be used again to calculate the trails of opening processes under test method A since the test samples were not moving during the opening processes. A new Matlab code was developed to calculate the trails of opening processes under test method B because the test samples were moving during the opening processed and the origin point of each frame picture was different.

Take 8.5 mm/s B1 test sample as an example, this test was performed by Instron tensile tester with fixture at a tensile speed of 8.5 mm/s and this test was labeled as 8.5 mm/s B1. 8.5 mm/s B1 test video was first edited in Adobe Premiere Pro to remove the redundant part and the total opening process time was 2.20s, which equaled to 132 frame pictures (60 frames per second). These 132 frame pictures could be exported by Adobe Premiere Pro, which represented the opening process from the start position to the end position. According to the Matlab programming code, all frame pictures had to be imported into Matlab for image processing. The

first frame picture was read and displayed by Matlab and the position of tab point could be located by clicking the mouse on the screen. Since the fixture was used in test method B, the test sample was moving during the opening process, which indicated that the origin point would also move from frame picture to frame picture. In this case, the tab point position should be located first by clicking the mouse, and then an X-Y axis will be built based on the origin point.
Once the position of tab point was located, X-coordinate and Y-coordinate values could be calculated based on X-Y axis per frame picture. After the analysis of the first frame picture was completed, the 7^{rd}, 13^{th}, 19^{th} …frame picture was read, displayed and processed in the same way until the last frame picture. After all frame pictures were processed, the X-coordinate and Y-coordinate values were converted from Matlab's Pixel values to real displacement in mm.

It is not necessary to read, display and process every frame picture from one test since there was no much tab point position difference between adjacent frame pictures when the total opening time is relatively long. For test sample 8.5 mm/s B1, tab point position was read, displayed and processed every six frames.

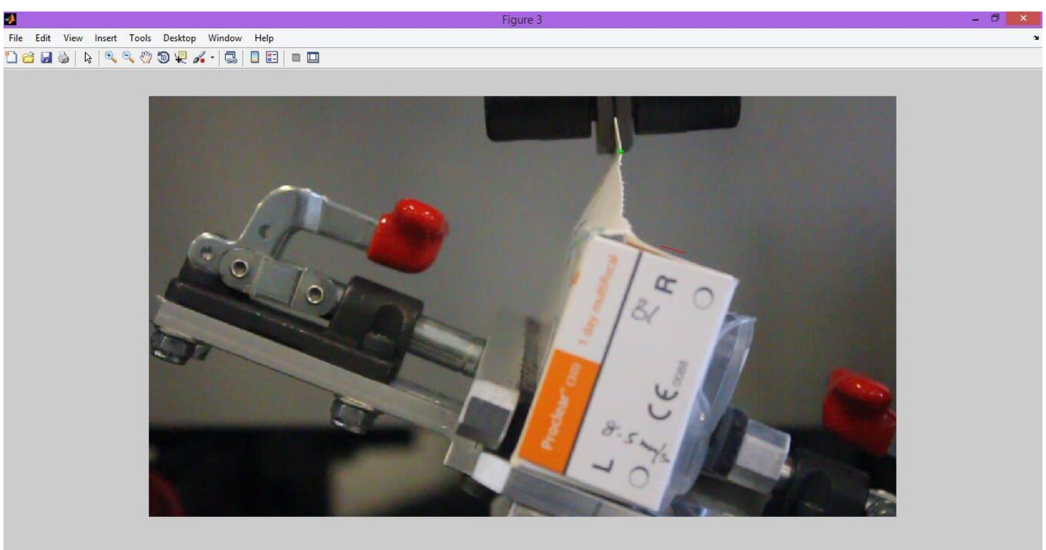


Figure 5.6 Locate the position of tab point

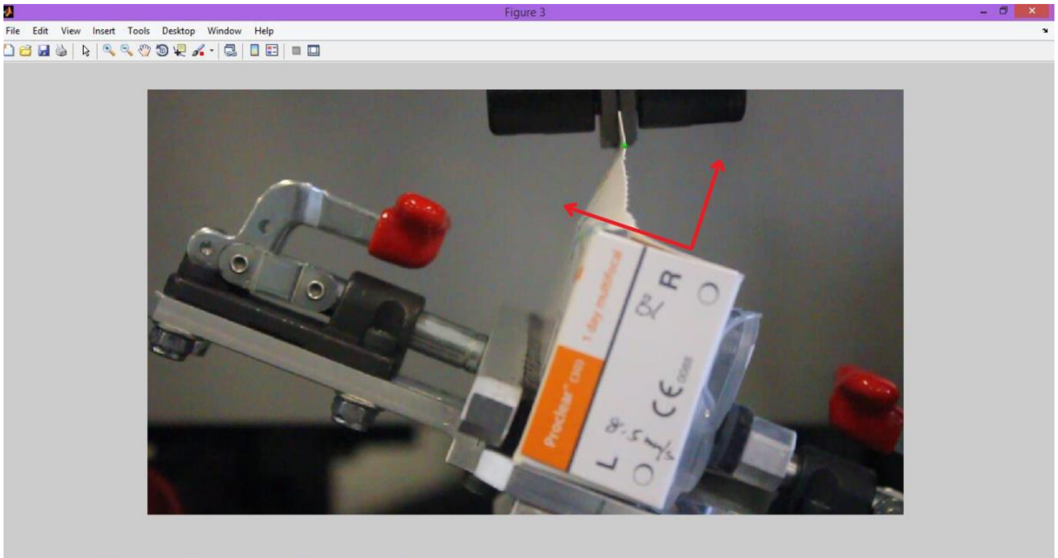


Figure 5.7 Build the axis on origin point

After all 30 test samples were processed and analyzed, all 30 test samples' opening time, final displacement in horizontal direction (X-Displacement) and final displacement in vertical direction (Y-Displacement) data were recorded in the table below.

Table 5.2 Summary of data under 2.125 mm/s

2.125 mm/s							
Test Method A	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**	**Test Method B**	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**
A1	9.683	20.408	26.410	**B1**	10.500	41.337	22.351
A2	9.133	19.800	24.600	**B2**	10.317	37.364	22.590
A3	9.517	23.709	25.510	**B3**	10.817	38.361	23.288
A4	9.933	22.809	26.710	**B4**	10.467	40.028	23.124
A5	9.767	19.957	28.046	**B5**	10.717	42.839	22.134
Mean	*9.607*	*21.337*	*26.255*	**Mean**	*10.564*	*39.986*	*22.697*
STD	*0.304*	*1.797*	*1.297*	**STD**	*0.201*	*2.207*	*0.495*

Table 5.3 Summary of data under 4.25 mm/s

4.25 mm/s							
Test Method A	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**	**Test Method B**	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**
A1	4.483	21.457	26.617	B**1**	3.967	31.509	24.072
A2	4.450	23.736	26.772	**B2**	4.333	32.877	26.781
A3	4.317	22.806	25.521	**B3**	4.767	32.530	24.572
A4	4.617	22.149	27.011	**B4**	4.500	33.998	26.827
A5	4.467	22.543	26.617	**B5**	4.750	32.957	24.296
Mean	*4.467*	*22.538*	*26.508*	**Mean**	*4.463*	*32.774*	*25.310*
STD	*0.107*	*0.841*	*0.575*	**STD**	*0.331*	*0.895*	*1.376*

Table 5.4 Summary of data under 8.5 mm/s

8.5 mm/s							
Test Method A	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**	**Test Method B**	**Time (s)**	**X-Dis. (mm)**	**Y-Dis. (mm)**
A1	2.133	23.078	26.064	B**1**	2.200	29.909	24.889
A2	2.183	22.272	26.346	**B2**	2.300	31.499	26.668
A3	2.400	22.374	29.299	**B3**	2.083	32.261	26.776
A4	2.150	21.188	25.747	**B4**	2.217	32.234	24.686
A5	2.200	23.882	26.270	**B5**	2.333	30.941	26.189
Mean	*2.213*	*22.558*	*26.745*	**Mean**	*2.227*	*31.369*	*25.842*
STD	*0.108*	*1.002*	*1.446*	**STD**	*0.098*	*0.984*	*0.990*

According to the table above, both test method A and test method B had a relatively small standard deviation in opening time, final displacement in horizontal direction (X-Displacement) and final displacement in vertical direction (Y-Displacement) at three different tensile speeds, which indicated that the opening process of mechanical test method was a stable and consistent opening process. The matlab data also showed that the time-displacement curves were close within each subgroup. Thus, it was acceptable to use one single test’s time-displacement curve as an example to illustrate the subgroup.

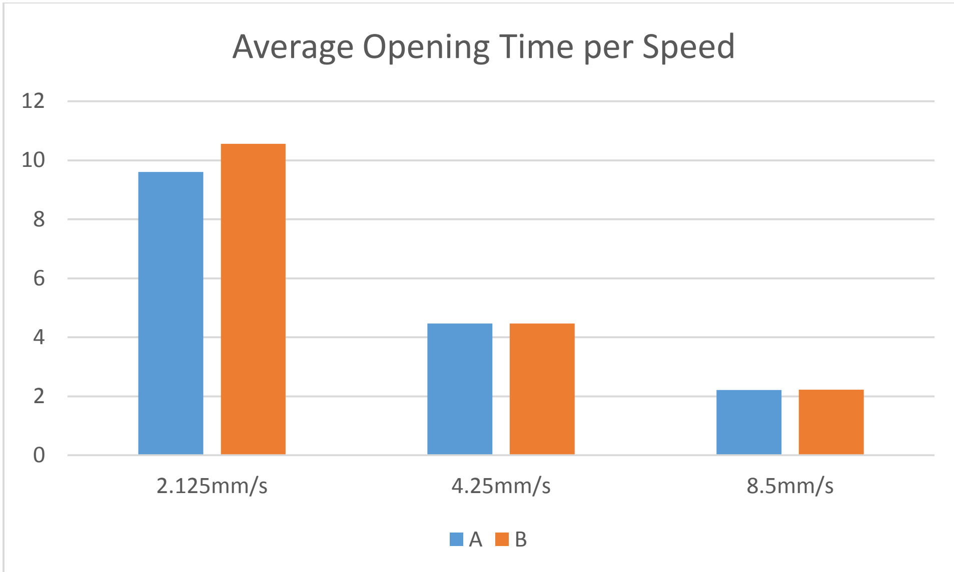


Figure 5.8 Average opening time per speed

It was found that for both test method A and B, the average opening time decreased dramatically when tensile speed increased from 2.125mm/s to 4.25mm/s to 8.5mm/s. When tensile speed was 2.125mm/s, test method B's average opening time was 10.564, which was 0.957s longer than test method A's average opening time. When tensile speed was 4.25mm/s, test method A had an average opening time of 4.467s and test method B had an average opening time of 4.463s, the time difference was only 0.004s. When tensile speed reached 8.5mm/s, test method A's average opening time was 2.213s while test method B's was 2.227s, the difference time was only 0.14s. Thus, it was found that when tensile speed was 2.125mm/s, test method A and test method B had a very close average opening time. When tensile speed was 4.25mm/s and 8.5mm/s, test method A and test method B's average opening time were almost the same.

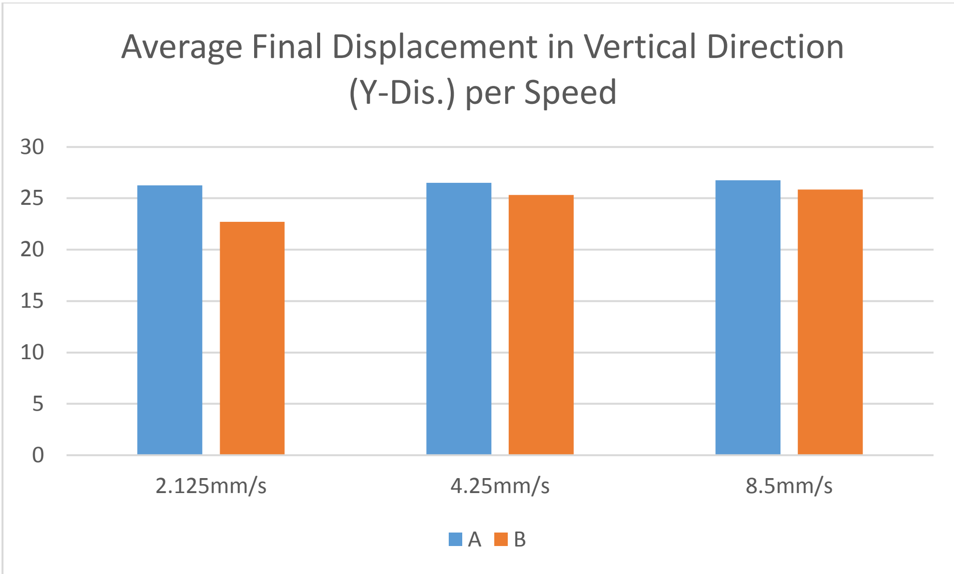


Figure 5.9 Average final displacement in vertical direction per speed

For both test method A and B, the average final displacement in vertical direction had a slight increase when tensile speed increased from 2.125mm/s to 4.25mm/s to 8.5mm/s. When tensile speed was 2.215mm/s, test method A's average final displacement in vertical direction was 26.255mm, which was 3.558mm longer than test method B's 22.697mm. When tensile speed was 4.25mm/s, test method A's average final displacement in vertical direction was 26.508mm, which was 1.198mm longer than test method B's 25.31mm. When tensile speed reached 8.5mm/s, test method A's average final displacement in vertical direction was 26.745mm, which was 0.903mm longer than test method B's 25.842mm. Even though test method A's average final displacement in vertical direction was always higher than test method B's at all three tensile speeds, the average displacement differences between test method A and test method B were relatively small and all average final displacement data were close to each other within two test methods. Thus, from the average final displacement in vertical direction's perspective, there was no significant difference between test method A and test method B.

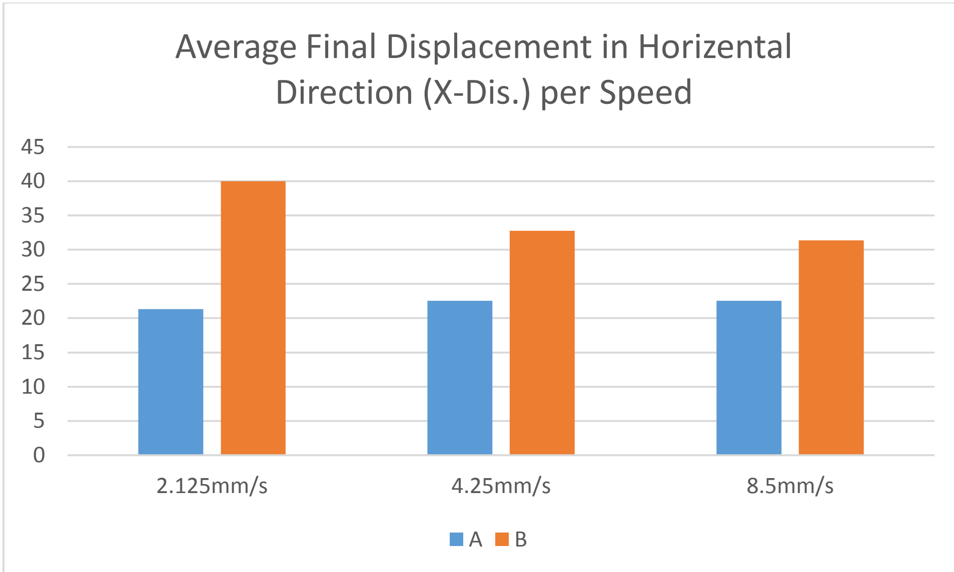


Figure 5.10 Average final displacement in horizontal direction per speed

For test method A, the average final displacement in horizontal direction had a slight increase when tensile speed increased from 2.125mm/s to 4.25mm/s to 8.5mm/s. For test method B, the average final displacement in horizontal direction dropped from 39.986mm to 32.774mm when tensile speed increased from 2.125mm/s to 4.25mm/s. Then it slightly dropped again to 31.369mm when tensile speed reached 8.5 mm/s. When tensile speed was 2.215mm/s, test method B's average final displacement in horizontal direction was 39.986mm, which was almost 90% longer than test method A's 21.337mm. When tensile speed was 4.25mm/s, test method B's average final displacement in horizontal direction was 32.774mm, which was almost 50% longer than test method A's 22.538mm. When tensile speed reached 8.5mm/s, test method B's average final displacement in horizontal direction was 31.369mm, which was about 40% longer than test method A's 22.558mm. It was found that test method B's average final displacement in horizontal displacement was always higher than test method A's at all three speeds and the differences between both test methods were significant. Thus, the comparison between test method A and B indicated that the utilization of the fixture would result a great impact on final displacement in horizontal direction. In this case, the utilization of the fixture will enhance the final displacement in horizontal direction and the percentage of increase dropped when tensile speed rose from 2.125mm/s to 4.25mm/s to 8.5mm/s.

- **Instron Data**

All 30 test samples' tear force values were recorded by Instron tensile tester as table below.

Table 5.5 Summary of Instron tear force data under three speeds

Instron Tear Force											
2.125mm/s				**4.25mm/s**				**8.5mm/s**			
Test method A	**Tear Force (N)**	**Test method B**	**Tear Force (N)**	**Test method A**	**Tear Force (N)**	**Test method B**	**Tear Force (N)**	**Test method A**	**Tear Force (N)**	**Test method B**	**Tear Force (N)**
A1	4.24	**B1**	4.57	**A1**	3.97	**B1**	3.72	**A1**	3.43	**B1**	4.39
A2	4.50	**B2**	5.43	**A2**	4.05	**B2**	3.87	**A2**	4.00	**B2**	4.05
A3	5.17	**B3**	4.79	**A3**	3.58	**B3**	5.26	**A3**	4.81	**B3**	4.3
A4	5.6	**B4**	4.95	**A4**	4.93	**B4**	5.34	**A4**	4.88	**B4**	4.22
A5	4.79	**B5**	5.58	**A5**	3.97	**B5**	5.49	**A5**	5.61	**B5**	3.78
Mean	*4.86*	**Mean**	*5.064*	**Mean**	*4.1*	**Mean**	*4.736*	**Mean**	*4.546*	**Mean**	*4.148*
STD	*0.539*	**STD**	*0.427*	**STD**	*0.498*	**STD**	*0.864*	**STD**	*0.845*	**STD**	*0.240*

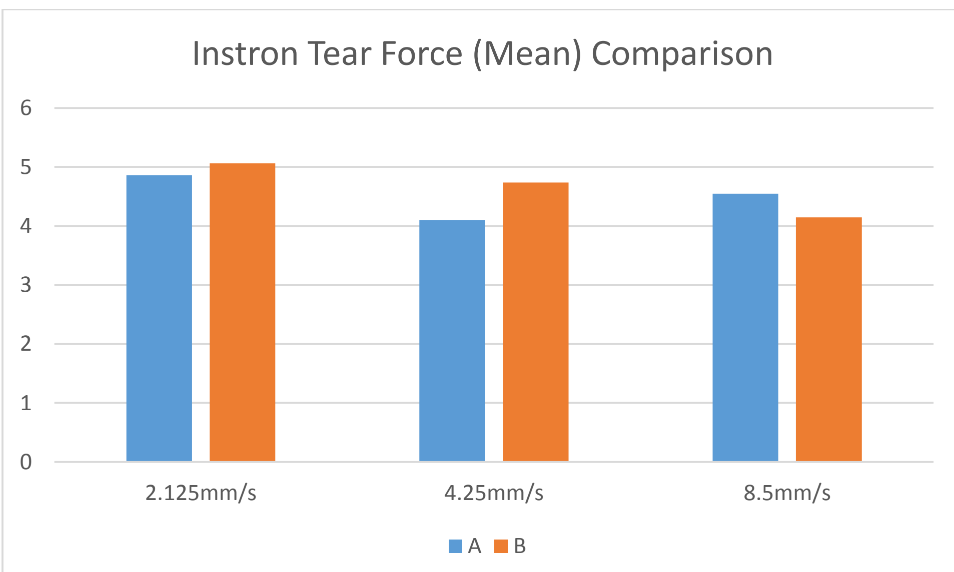
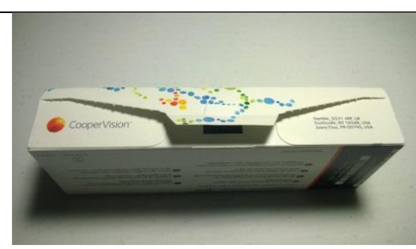


Figure 5.11 Instron Tear Force (Mean) Comparison

For test method A, the tear force’s mean value decreased from 4.86N to 4.1N when tensile speed increased from 2.125mm/s to 4.25mm/s, then the mean value increased from 4.1N to 4.546N when tensile speed increased from 4.25mm/s to 8.5mm/s. For test method B, the tear force’s mean value dropped from 5.064N to 4.736N when tensile speed increased from 2.125mm/s to 4.25mm/s. Then it dropped again from 4.736N to 4.148N when tensile speed reached 8.5mm/s. When tensile speed was 2.125mm/s, test method B’s tear force mean value was 5.064N, which was 0.204N or 4% larger than test method A’s 4.86N. When tensile speed was 4.25mm/s, test method B’s tear force mean value was 4.736N, which was 0.636N or 15% larger than test method A’s 4.1N. However, when tensile speed reached 8.5mm/s, test method A’s tear force mean value was 4.546N, which was 0.398N or 10% larger than test method B’s 4.148N. Thus, it was found that when tensile speed was 2.125mm/s, there was no significant difference between both test methods on tear force. When tensile speed was 4.25mm/s, test method B had a 15% larger tear force mean value than test method A’s. But when tensile speed changed to 8.5mm/s, test method A had a 10% larger tear force mean value than test method B’s.

- **Damage Profile**

Table 5.6 Summary of damage profile

Sample Number	**Defect ‘’Start’’ and ‘’End’’ Location**	**Location of Defect**	**Type of Defect**	**Picture**
Sample 8.5mm/s A5	Defects started to happen and end at the last perforation dot on both left and right sides.	Left side near the corner and right side near the corner	Unopened perforation	

Only 1 of 30 test samples was found with defects, which was test sample 8.5mm/s A5. From the damage profile chart above, it was found that 8.5mm/s A5 had unopened perforation on both left and right side, no delamination was found. The locations of defects were very close to left side corner and right side corner. The defects started to happen and end at the last perforation dot on both left and right sides since the last perforation dot on both left and right sides was not torn apart.

6. Conclusion and Recommendations

According to previous study, the typical opening pattern had an overall average opening time of 0.938s, overall average final displacement in vertical direction of 41.30mm and overall average final displacement in horizontal direction of 20.66mm.

- Opening Time

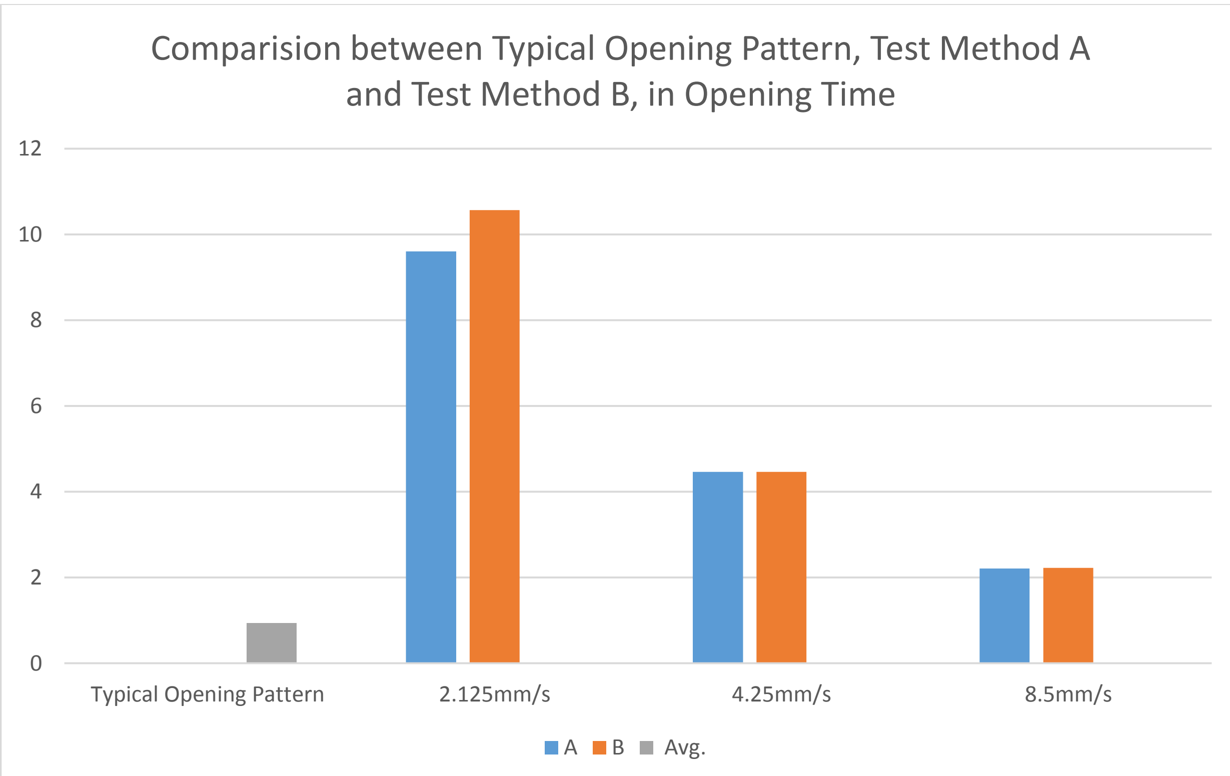


Figure 6.1 Comparision between Typical Opening Pattern, Test Method A and Test Method B, in Opening Time

The previous study indicated that both test method A and test method B's average opening time decreased when tensile speed increased and there was no significant difference between both two test methods on opening time when tensile speed was the same. In order to simulate the typical opening pattern, the new test method's opening time should be close to typical opening pattern's average opening time of 0.938s. Thus, opening time under 8.5 mm/s tensile speed was better than opening time under tensile speed 4.25 mm/s and 2.125 mm/s because under tensile speed 8.5 mm/s, test method A had an opening time of 2.213 and test method B had an opening time of 2.227, which were the closest opening time to the typical opening pattern's 0.938s.

- Displacement in horizontal direction (X)

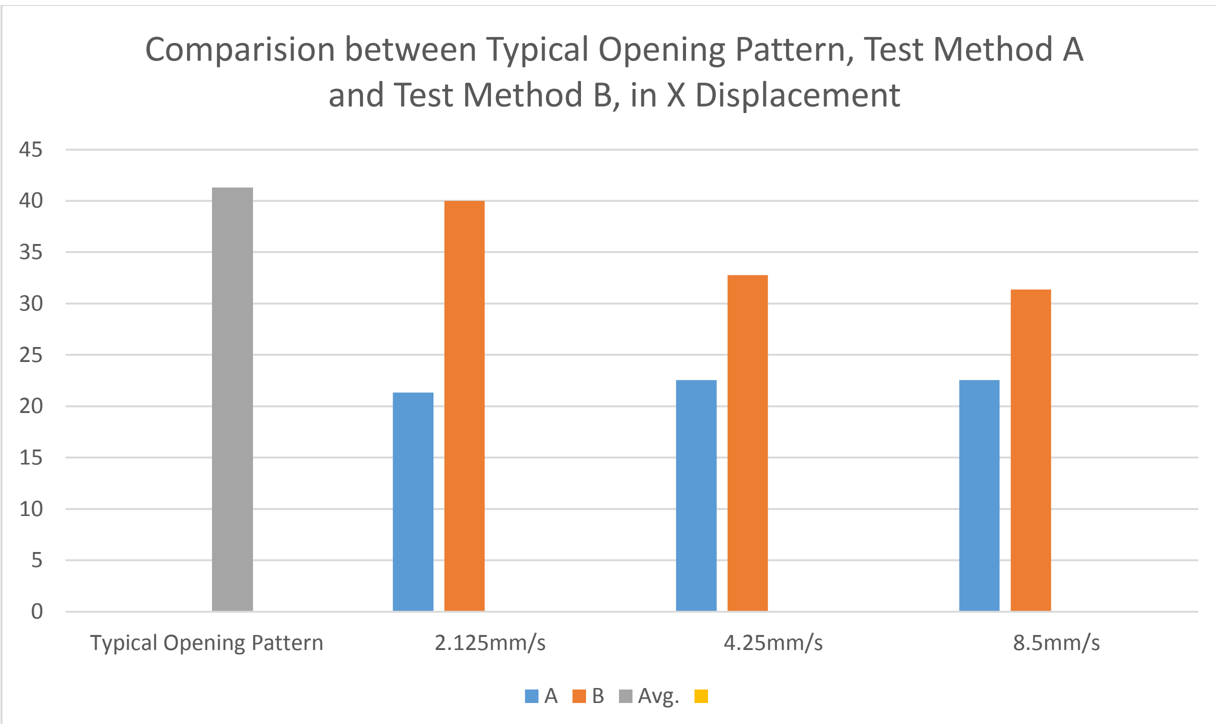


Figure 6.2 Comparision between Typical Opening Pattern, Test Method A and Test Method B, in X Displacement

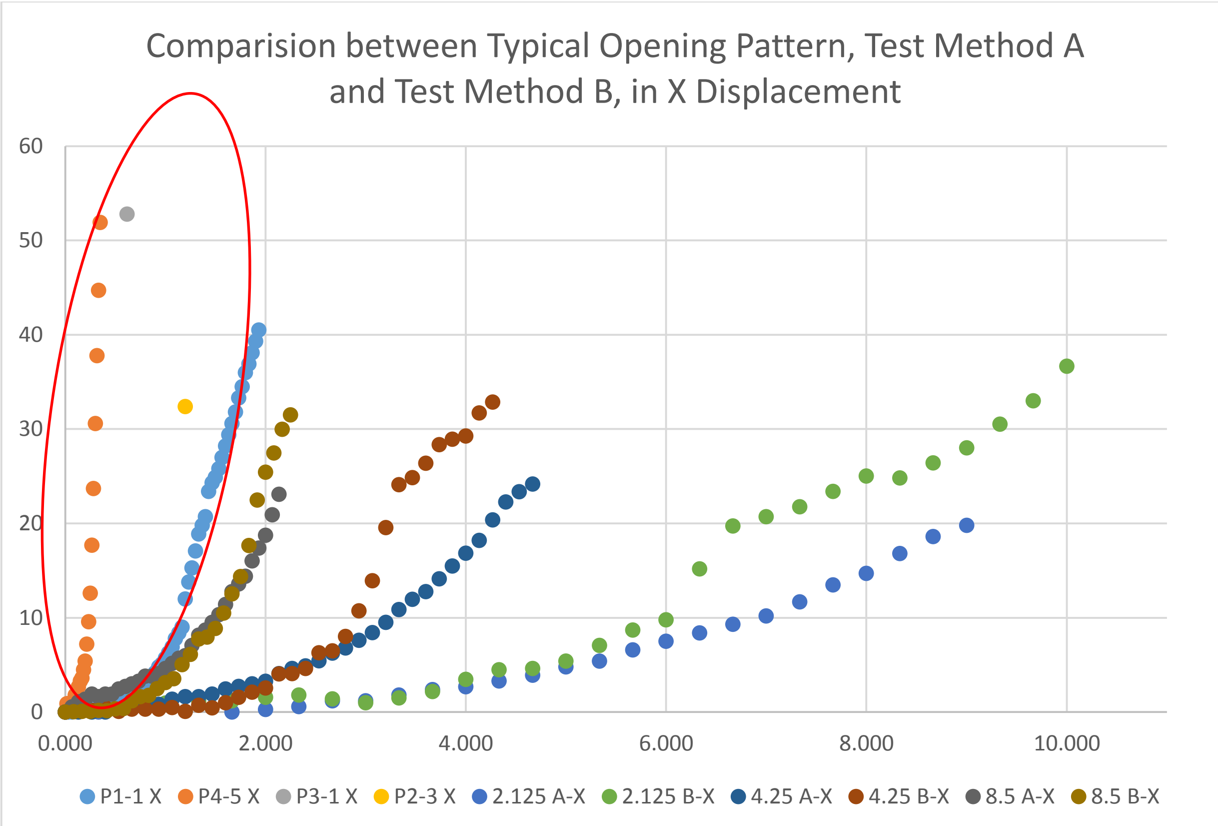


Figure 6.3 Comparision between Typical Opening Pattern, Test Method A and Test Method B, in X Displacement

From the previous study it was found that test method B's average final displacement in horizontal direction was 90%, 50% and 40% longer than test method A's when tensile speed was 2.125mm/s, 4.25mm/s, 8.5mm/s. From the chart above, when tensile speed was 2.125mm/s, test method B's average final displacement in horizontal direction was 39.986mm, which was very close to typical opening pattern's 41.3mm. Even though test method B's average final displacement in horizontal direction dropped to 32.774mm and 31.369mm when tensile speed increased, test method B's value was always significantly higher than test method A's. Thus, the comparison between typical opening pattern, test method A and B indicated that the utilization of the fixture was effective and would result a great impact on final displacement in horizontal direction. In this case, the utilization of the fixture will enhance the final displacement in horizontal direction, which was more close to typical opening pattern's value, compared to the test methods without the fixture. The utilization of the fixture improves the test method since it has a better simulation to the typical opening pattern.

- Displacement in vertical direction (Y)

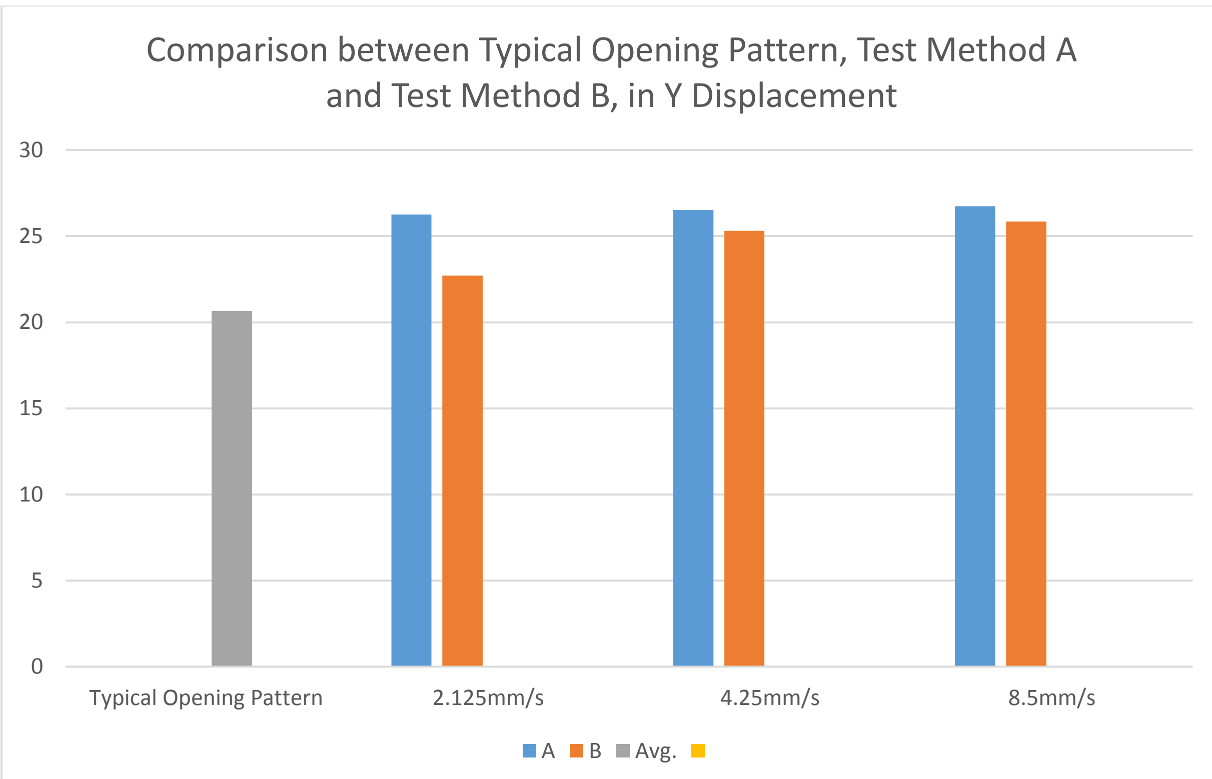


Figure 6.4 Comparison between Typical Opening Pattern, Test Method A and Test Method B, in Y Displacement

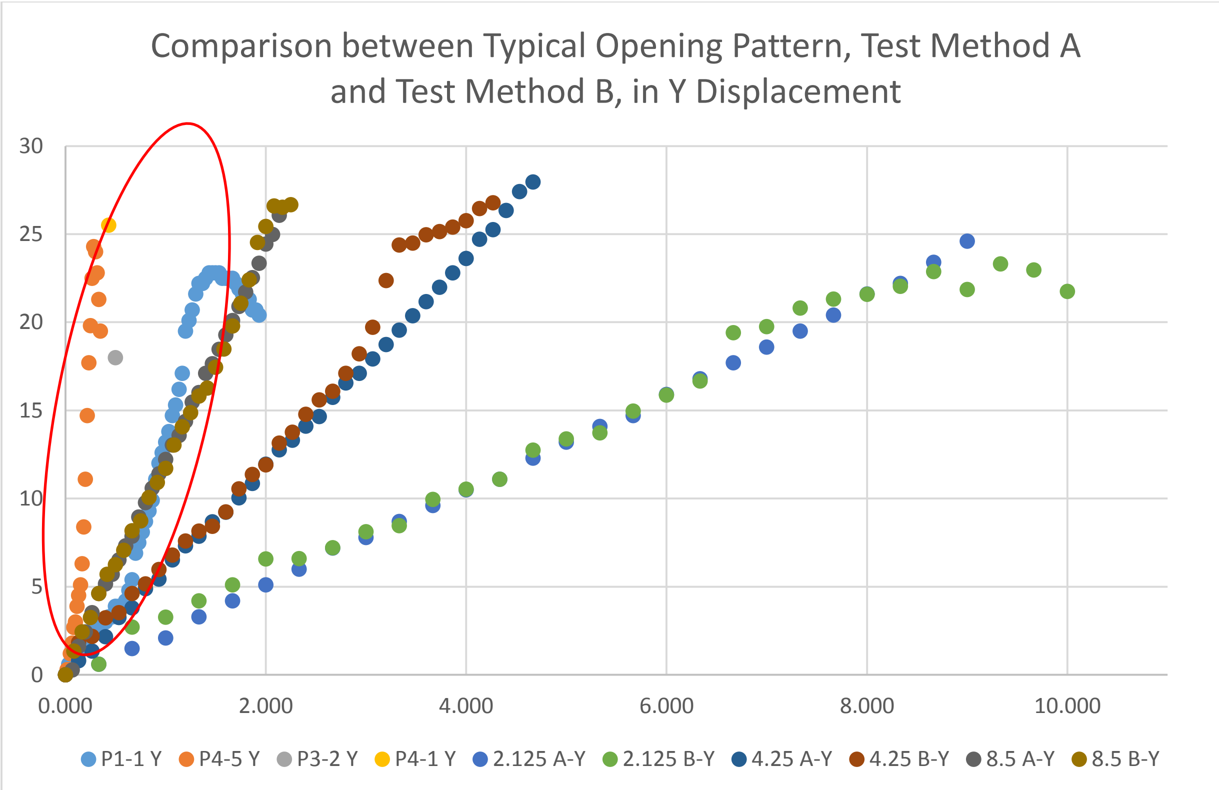


Figure 6.5 Comparision between Typical Opening Pattern, Test Method A and Test Method B, in Y Displacement

Even though test method A's average final displacement in vertical direction was always higher than test method B's at all three tensile speeds, the average displacement differences between test method A and test method B were relatively small and all average final displacement data were close to each other within two test methods. Thus, from the average final displacement in vertical direction's perspective, there was no significant difference between test method A and test method B. When compared test method A and B's average displacement in vertical direction to typical opening pattern's, it was found that when tensile speed was 2.125 mm/s, test method B was better than test method A since test method B under 2.125mm/s had a value of 22.697mm, which was the closest one to typical opening pattern's 20.66mm. Test method B was also slightly better than test method A when tensile speed increased to 4.25mm/s and 8.5mm/s but the differences were relatively small.

- Damage profile

6 out of 25 test samples were found with defects under typical opening pattern experiment while only 1 out of 30 test samples were found with defects under new test method validation experiment.

For typical opening pattern experiment, the 6 test samples had very similar type of defects, which was unopened perforations and delamination. The locations were all in the left side perforations close to the corner of carton except sample P1-2 which was in the right side. The “start” and “end” positions of defects were almost the same, they all started to happen at the perforations line. When people continued to lift the tab, the paper board started to delaminate until the front panel was lifted up. The end positon was the upper carton line.

For new test method validation experiment, it was found that 8.5mm/s A5 had unopened perforation on both left and right side, no delamination was found. The locations of defects were very close to left side corner and right side corner. The defects started to happen and end at the last perforation dot on both left and right sides since the last perforation dot on both left and right sides was not torn apart.

Thus, compared to typical opening pattern experiment’s defect rate (24%), the defect rate in new test method validation was very low (3%). The location and type of defects in two experiments were not exactly the same, but they both had the same defects like unopened perforations. There might be two reasons for this. First, since the Instron tensile tester could only have a maximum tensile speed of 8.5mm/s while typical opening pattern’s average speed was 30.07mm/s. The huge difference between tensile speeds might results a different defect rate, the perforations seemed to be opened without defects when tensile speed was really low. Second, when people opened a perforations, the force used by hands was not a consistent force while Instron's force was consistent, this might contributes to different type of defects, like delamination.

In conclusion, the utilization of fixture will not affect the opening time, it will slightly affect final displacement in vertical direction and it have a huge impact on final displacement in horizontal direction. Compared to tests method without the fixture, the utilization fixture will slightly increase final displacement in vertical direction and significantly increase final displacement in horizontal direction, which results final displacement values more closes to typical opening pattern's value. Thus, the utilization of fixture and Instron tensile tester is a more accurate and effective test method, to simulate typical opening pattern as a mechanical test method.

- Recommendations

The maximum tensile speed 8.5mm/s should be increased since the typical opening pattern's average speed was 30.07mm/s. By increasing the tensile speed, test method B could have an opening time closer to typical opening pattern's 0.94s, the current average opening time for test method B was 2.227s.

For final displacement in vertical direction, the test method B had a closer data of 22.697mm to typical opening pattern's 20.66mm when tensile speed was 2.125mm/s. For final displacement in horizontal direction, the test method B had a closer data of 39.986mm to typical opening pattern's 41.3mm. The differences will start to increase when tensile speed increases in both directions. Since tensile speed of 2.125mm/s was too slow and should not be used for future tests, we have to make sure the final displacement in both directions were still close to typical opening pattern’s value when tensile speed increases. In order to achieve this goal, the fixture could be further modified by adding an adjustable mechanism between pivot plate and pivot shaft. This mechanism could provide different frictions when pivot plate revolves around pivot shaft so that the final displacement in both directions could be adjustable even tensile speed was high.

Defects found in the test method was not exactly the same as the defects found in typical opening pattern because the test method still needs to be improved for a better simulation of typical opening pattern. By increased the tensile speed and modifying the fixture, the test method might reflect the defects in real world in a more accurate way since it is more close to typical opening pattern’s method.

The typical opening pattern experiment in this study was all performed by right hand. When people were asked to use their less used hands, they might tear perforations in a lower force and different directions, which might affects the typical opening pattern’s data and damage profiles. A further study could be conducted to compare the difference between left hand’s typical opening pattern and right hand’s typical opening pattern.

7. Reference

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ASTM D828-97(2002), Standard Test Method for Tensile Properties of Paper and Paperboard Using Constant-Rate-of-Elongation Apparatus (Withdrawn 2009), ASTM International, West Conshohocken, PA, 1997, www.astm.org.

8. Appendix A

```
clear all;
% close all;
% 1. change to image path
image_path = 'C:\Users\dxw1491\Desktop\P1-1';

raw_ind = 0;
% 2. change the index
for idx_img = 0:2:117
% 3. change the name, sequnce, 3d/2d
imgName = strcat(image_path,'\Sequence 01',num2str(idx_img,'%02d.jpg'));

img = imread(imgName);

figure;
imshow(img);
[x,y] = ginput;

raw_ind = raw_ind +1;
loc_xy_raw(raw_ind, :) = [x y];

end
num_points = size(loc_xy_raw,1)
t_1 = loc_xy_raw - repmat( loc_xy_raw(1,:), num_points, 1); % set origin to zero
t_2 = -t_1; % change direction

loc_xy_converted = t_2;

figure,plot(loc_xy_converted(:,2),loc_xy_converted(:,1));
% axis([0 350 0 350]);
% xlabel('x motion'); ylabel('y motion');
% grid on;

% xx = loc_xy_raw(:,1);
% yy = loc_xy_raw(:,2);
%
% xx = xx - xx(1);
% yy = yy - yy(1);
% figure,plot(xx,yy);
% figure,plot(fliplr(xx),fliplr(yy))

% t_1 = loc_xy_raw - repmat( loc_xy_raw(1,:), 3, 1); % set origin to zero
% t_2 = -t_1; % change direction

% loc_xy_converted = t_2;
```

```
% save data.mat loc_xy_raw loc_xy_converted
```

9. Appendix B

```
clear all; clc; close all;

image_path = cd;

sp = 640;
Range = 0:sp:644;
Dis_Matrix = zeros(numel(Range),2);

i = 0;
figure,
for idx_img = Range
    i = i+1;
    imgName = strcat(image_path,'\B2_1',num2str(idx_img,'%03d.jpg'));
    im = imread(imgName);
    imshow(im);
    pause(0.1);


    % 3 points sequence:
    % (1) point to be detected
    % (2) point on x-axis
    % (3) original pint

    [x_coord, y_coord]=ginput(3);


    point_position = [x_coord(1) y_coord(1) 1];
    x_point = [x_coord(2) y_coord(2) 1];
    origin = [x_coord(3) y_coord(3) 1];
    % y_point = [x_coord(4) y_coord(4) 1];

    x_axis = cross(x_point,origin);
    ay = -x_axis(2);
    by =  x_axis(1);
    cy = -ay*origin(1)-by*origin(2);
    y_axis = [ay,by,cy];

    % y_axis = [x_axis(2),x_axis(1) 1];
    % y_axis = cross(y_point,origin); y_axis = y_axis./y_axis(end);

    dist_x = abs(x_axis*point_position')/sqrt(x_axis(1)^2+x_axis(2)^2);
    dist_y = abs(y_axis*point_position')/sqrt(y_axis(1)^2+y_axis(2)^2);

    Dis_Matrix(i,1) = dist_x;
```

```
    Dis_Matrix(i,2) = dist_y;

    figure,imshow(im);
    hold on;
    scatter(point_position(1),point_position(2),'g*')
    plot([x_point(1) origin(1)],[x_point(2) origin(2)],'r')

    % plot([y_point(1) origin(1)],[y_point(2) origin(2)],'b')

    message1 = sprintf('Pixel counts from point to x axis is : %d',ceil(dist_x));
    message2 = sprintf('Pixel counts from point to y axis is : %d',ceil(dist_y));
    disp(message1);
    disp(message2)

end
```