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EVALUATION AND OPTIMIZATION OF A VERTICAL FORM-FILL-SEAL PRODUCTION MACHINE FOR FLEXIBLE PACKAGING PAPERS

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ABSTRACT

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Evaluation and optimization of a vertical form, fill and seal production machine for flexible packaging papers

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Vertical form fill seal machines are commonly used in packaging industries to produce pillow and block bottom bags for dried products. This research evaluated and optimized the machine for fiber-based materials and compared the runnability with thermoplastic material using three different sealing tool profiles with 140 mm width forming shoulder. There are three main heat sealing parameters, sealing temperature, dwell time and sealing pressure. Each of these parameters can influence the seal quality significantly to achieve satisfactory seal strength, airtightness and adhesive bond. The initial task investigated and developed the heat sealing processing window between the seal strength and sealing parameters (sealing temperature and dwell time) using contour plots and 3D mapping relationships. The peel strength test was conducted using T-peel method with 90° pulling direction at constant rate of 300 mm/min with Shimadzu AGS-1kNX. The test samples were prepared as per the ASTM F88 guidelines. Three major failure modes were observed from the peel test. At low temperatures, about 100 °C, most of the materials experienced easy peel because the seal strength is lower than the strength of the adhesive layer. At higher temperature, above 110 °C, the molecules forms interdiffusion of chains leading to delamination and separation of seal from the sealing layer or in worst case, the material gets teared at the edge of the seal. Detailed analysis with each materials and corresponding sealing tool is thoroughly explained in the report. After the production of pillow bags, major wrinkles were observed on the surface of the bags due to sharp bending angle and fillet edge of the forming shoulders. 3D profilometer, Keyence VR 3200, was used to examine the surface roughness. The roughness value tripled on average with Fiber 85 and quadrupled with Fiber 120 because the Fiber 85 has lower stiffness and more flexibility than Fiber 120. Several suggested improvements and suggestions for future tests are further discussed.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols and Units

SS	Seal Strength [N/mm]
Ra	Average Roughness [µm]
Rz	Highest Roughness [µm]
v	Constant Rate [mm/min]
%M	Moisture Content

Abbreviations

R&D	Research and Development
RH	Relative Humidity
FFS	Form Fill Seal
VFFS	Vertical Form Fill Seal
PE	Polyethylene
OPP	Oriented Polypropylene
PET	Oriented polyester
LLDPE	Low-Density Polyethylene
HDPE	High Density Polyethylene
MCPP	Metallic Cast Polypropylene
LOD	Loss of Drying
PTFE	Polytetrafluoroethylene
COF	Coefficient of Friction
FEM	Finite Element Method
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering

1 INTRODUCTION

There are various kinds of packaging products used in our day to day life. Approximately 70 % of the packaging is used for food and drinks, where the rest is from the other sector such as beauty, healthcare, clothing, electronics, etc. (Emblem & Emblem 2012, p. 7). The following chapter discusses general background and objectives of the research.

1.1 Background

Food packaging is an essential base to preserve food safely, ease of transportation and to protect the content from crushing, damage or even improper temperature and exposer to light. Packaged products are usually sealed to prevent contamination with bacteria, toxins, oxygen, and moisture, thus increasing shelf life. (Hughes 2007, p. 695)

In 2019, the total global packaging was valued $917. The search showed that the packaging is increasing at a steady rate of 2.8 %. By 2024, the global packaging will be valued $1.05 trillion. (Pira, 2020) According to Smithers Pira source, in 2016, the world packaging was divided to 35.7 % paper and paperboard, 23.3 % flexible materials, 18.2 % rigid plastics, 12.2 % metals such as steel and aluminum and 6.6 % glass, and the remaining 4 % are others made up of materials such as wood and textile (All4pack.com 2018, p. 4).

Plastic packaging has existed since the 1940s and major R&D has been considered to develop a low-cost process and provide suitable plastic materials for different applications (Emblem & Emblem 2012, p. 8). As the global population growth is on a rise, industrialization and customer product's demands has increases the global waste of plastic packaging. It is estimated that the global consumption of plastic is more than 200 million tonnes, with an annual growth of 5% (Siracusa et al. 2008, p. 634). Plastic packaging are source of thermoplastic polymers (non-biodegradable) which consists of toxic elements that causes negative impact to the landfills, ocean, river, etc. (Emblem & Emblem 2012, p. 9)

In comparison to plastic packaging material, paper provides many advantages. It is a green (eco-friendly), bio-degradable and readily recyclable. Paper materials are cellulose based which are known to be decomposable. In terms of its strength, it is much stronger at a low cost. Currently, many European and international companies are developing flexible paper packaging material which are glue laminated or extrusion coated paper material with thin polyethene. Other kinds of paper-based materials are of dispersion coating and consists of no or very little polymer. To appropriately seal the paper and paperboard materials, heat sealing, wetting and adhesion method is required. (Savolainen 1999, pp. 12-36)

1.2 Motivation

As the carbon footprint is on a rise, the urge to develop green and sustainable packaging material accelerates. The packaging industries plays an important role to develop sustainable solution to our environment to reduce global carbon footprint. Majorities of the leading pulp and paper industries in Finland such as Stora Enso, UPM, Paptic, etc have invested heavily to provide sustainable packaging solution.

The motivation of this thesis is to evaluate and optimize the performance of vertical form-fill-seal (VFFS) machine for futuristic fiber-based material. According to literature studies, majority of applied commercial applications utilize thermoplastic packaging materials for VFFS machine. The Laboratory of Packaging at LUT University would be among the first to conduct scientific research using flexible packaging paper for VFFS machine. Therefore, the long term commitment is to provide a sustainable flexible packaging solution to Finnish and international market.

1.3 Objectives

The objective of this work is to optimize and evaluate the performance of VFFS machine using flexible packaging paper. To achieve this goal, the first aim is to compare the runnability of different thicknesses of the flexible paper-based material with thermoplastic material using various sealing tool profiles. This would give us good insight to present the hindering factors of using flexible paper based material. The second aim is to suggest several improvements for further development of VFFS machine.

To achieve the objectives mentioned above, the research will unfold the influence of process parameters which influence the seal quality such as heat sealing temperature, heat sealing pressure and dwell time. The correlation and influence of these parameters with each other will open new era of packaging technologies especially to companies.

1.4 Research problems and questions

Research and development (R&D) in the field of heat sealing is complex. Determining optimal heat sealing parameters can be critical as each material behaves differently due to variety of unique molecular structure and sealing adhesive layers. Additionally, there are no freely available conference literatures from packaging industries that could provide us with necessary details of their products. The heat sealing technology is usually kept confidential to the public which create challenges in research.

With the current EU regulations, most of packaging industries are required to shift towards sustainable and environmentally green packaging solution. Therefore, systematic literature review is conducted to investigate the heat sealing technology of fiber-based materials. However, majority of the research articles are based on heat sealing of thermoplastic polymers or on laboratory heat sealing tests.

It is expected that there will be several challenges to conduct this research as there are no relevant literature studies on heat sealing of fiber-based materials. The theoretical knowledge of this research experiment is based on available literature studies on heat sealing of thermoplastic polymers.

The thesis will unfold significant knowledge of heat sealing and suggest possible improvements of VFFS packaging machine using the fiber-based material. For these reasons, it has brought a great attention to evaluate and optimize the VFFS machine using the fiber-based material. Below are several important research questions which will be investigated.

The main research questions are:

- What are the possibilities of fiber-based packaging materials with VFFS production machine?
- What are the limitations caused by the VFFS machine?
- What are the key issues with the fiber-based material?
- How to improve the runnability of the fiber-based materials?
- What are the limiting factors of the fiber-based material such as the material properties and peel strength?
- What is the appropriate heat-sealing time, temperature and pressure on for fiber-based material?

The sub-questions are:

- What is the effect of heat sealing time, temperature and pressure on the runnability of fiber-based materials?
- How to improve the runnability of the fiber-based materials?
- What is the peel strength and surface roughness of fiber-based materials?
- How to improve the performance of VFFS machine?

1.5 Scope

The primary goal of the thesis is to investigate and evaluate the VFFS machine using different sealing tool profiles. The focus is to improve the runnability of fiber-based material and compare it with thermoplastic material. There are several aspects that needs to be investigated during this master's thesis.

Firstly, a literature study would focus on the theoretical background for heat sealing, fiber based materials and identify the critical heat sealing factors. Secondly, investigation of the appropriate process parameters and their effect with different sealing profiles. This would allow us to determine the processing window for the VFFS machine. Thirdly, to determine the effect of the material thickness on the runnability of the materials. At last, to investigate the effect of surface roughness of pillow bags with different shoulder types.

2 LITERATURE REVIEW

Literature review will focus on the fundamentals of heat sealing, heat sealing factors, basic mechanism of vertical form fill seal machine and types of possible bags. A brief introduction on different types of flexible packaging materials are discussed.

2.1 Vertical Form-Fill-Seal Machine

Vertical Form-Fill-Seal (VFFS) machines are widely used to produce bags for packaging dried products such as peas, salt, snack food or even frozen prepared vegetables from a single reel of flat film (Dudbridge 2016, p. 97). VFFS system comes with two main types, intermittent motion and continuous motion, depending on their usage. The intermittent motion operates with start and stop motion. Continuous motion VFFS machine are highly preferred in industries for high speed packaging with an excellent efficiency as compared to intermittent motion VFFS type. (Song, Liu and Liu 2011, p. 282)

Chapter 3 from the Handbook of Seal Integrity in the Food Industry by Dudbridge (2016) stated that the VFFS machine consist of five main accessories including film handling system, shoulder forming, longitudinal sealing, filling process and top/bottom sealing.

The typical arrangement of VFFS machine is presented in figure 1. The process starts with placing the packaging material around the reel. The film handling system then draws the roll through series of rollers arranged in positions to control the tension and guide the film accordingly. The film is then delivered over forming shoulder which smoothly forms into the forming tube with the belt transport mechanism. The belt transport mechanism creates a friction between the belt and the film to create a pulling action. The forming tube of the film forms a bag shape to prepare for the filling of the materials. The filling process is the delivery of products by the fall of gravity towards a newly formed bag. The timing of the filling process is precisely adjusted to guarantee that the bag is cross sealed from the top to form the complete pouch. (Desoki, Morimura and Hagiwara 2010, pp. 31-32; Dudbridge 2016, pp. 100-110)

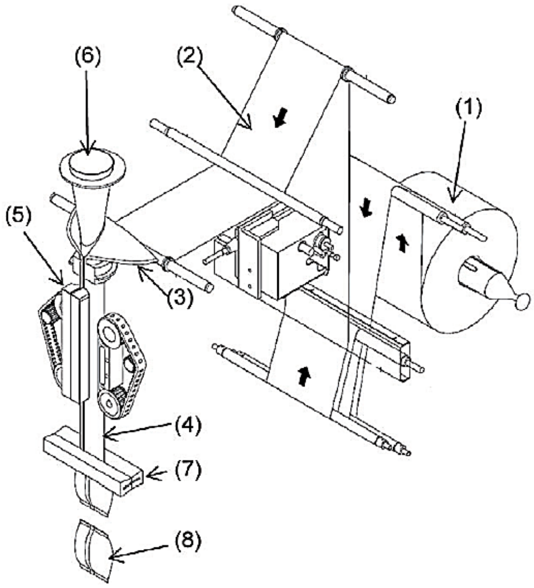


Figure 1. Typical design for vertical form-fill-seal machine (Reproduced from Desoki, Morimura and Hagiwara 2010, p. 32).

The forming shoulder system has multiple functions which are engineered precisely. It plays an important role to guide and deliver the film into the forming tube. However, its roughness and design could impact the performance of the bags passed through the forming tube. The forming shoulder is designed to adjust the width of the packaging bag. It guides to bring the outer edges of the film together and overlap the edges formed in the forming tube. The seaming operation consist of three seams: longitudinal, top and bottom. The longitudinal sealing system would heat seal the overlapped edges formed in the forming tube. The film is passed to the end of the filling tube where the pairs of sealing jaws form the bottom seal on the package to prepare for the filling process. The top sealing is first formed by the sealing jaws. Then the bottom seal is formed for the next bag using sealing jaws and product is filled again from the tube. (Desoki, Morimura and Hagiwara 2010, p. 33), (Dudbridge 2016, pp. 107-119)

Most kinds of form fill seal (FFS) machines consists of bar sealing jaws. The VFFS machine has a built-in heat jaw sealing mechanism. (Dudbridge 2016, p. 116) The principle of jaw sealing mechanism is presented in figure 2. There are various types of jaw design and each design has a great influence on seal quality and strength. The jaws are selected depending on the application and requirements. Serrated or crimp jaws are commonly used to impose extra strength, improve the seal appearances and to compensate for variations in film thickness on form fill seal machines. (Theller 1989, pp. 72-73)

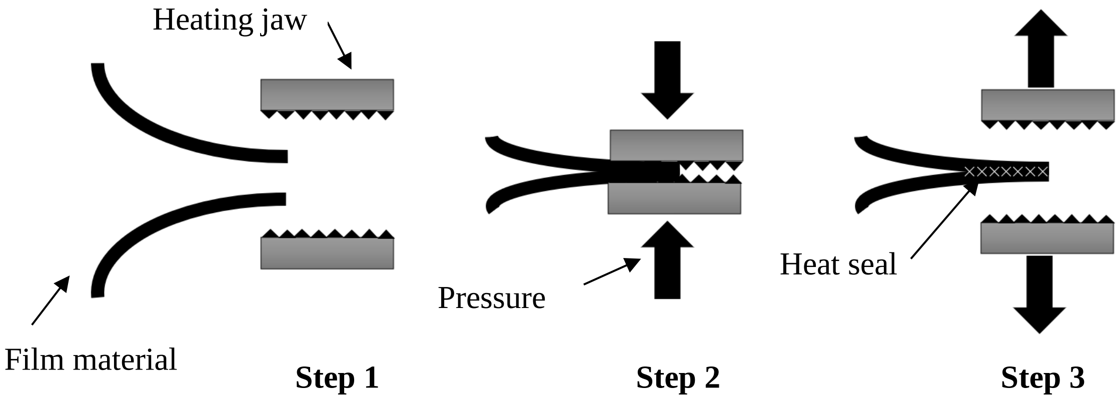


Figure 2. Jaw heat sealing mechanism.

2.2 Flexible packaging material

Packaging materials play a significant role to preserve the physical quality, merchandising, protect from contamination and to ease for transport of products. Majority of the packaging materials are in the form of rigid or flexible. Rigid materials may include cans, jars, glass, etc. Flexible packaging is a material that can be wrapped which include major group of packaging materials such as thermoplastic polymers, cellulose based material, cloths, vegetable fibers. (Raheem 2013, p. 117)

Until now, majority of the VFFS applications use thermoplastic materials. There are various kinds of materials used for the VFFS machine and among them are thermoplastics polymers. These include simple polyethylene films used for packing potatoes to multilayer polymer films for higher packaging needs (Dudbridge 2016, p. 111). Other typical films include oriented polypropylene (OPP) and oriented polyester (PET) which are typically used for food snacks such as candies, cookies and bakery products (Clark & Wagner 2002, p. 116).

Due to the environmental concerns, sustainable packaging, cellulose-based packaging, remains as an area of ongoing research focus to reduce the global emissions, packaging waste and energy consumption (Kirwan, Plant, & Strawbridge, W. 2013, pp. 205-209). It is increasingly important to utilize biodegradable materials for food packaging and other products to reduce waste.

Researchers Clark & Wagner (2002) are the only scientists who used VFFS for flexible packaging material. However, their focus of research was based on OPP and PET materials. In their paper, they have evaluated and optimized the VFFS machine to evaluate the plastic film properties such as coefficient of friction (COF), sealing temperature, hot tack effect. As the VFFS machine operates at high production rate, they included several suggestions.

- it is increasingly important to have material with good strength.
- material should have low COF so that it can easily flow over the forming shoulder.
- Sealing temperature and hot tack ranges depend on the material properties of the film material.

Apart from food industries, flexible packaging materials are used in many aspects of sterile medical device packaging. Medical devices need to fulfill package integrity. The packaged samples need to fulfill its sterility, storage, absorbs shock, crushing, humidity, heat, etc. until the time of use (Fuente and Bix, 2009, p. 714) Typical materials used for packaging medical devices include paper, Tyvek**®,** aluminum, plastics such as (LLDPE, PP, PET) (Fuente and Bix, 2009, p. 717; (Sterling, 2016))

Sealing of medical device packaging is critical to maintain the sterility until the time of use. In practice, peelable seals are recommended in today’s medical packaging. Paper with polymer (latex) has been highly valued as pouches and lidding combination as it provides clean peelable seal. (Sterling, 2016)

2.3 Types of bags

The VFFS machine is capable to produce two types of bags, pillow and block bottom bags. The geometry of the bag is formed when the film passes through the forming tube. The tube is in usually in cylindrical shape to provide smoothness at high speed (Desoki, Morimura and Hagiwara 2010, p. 32). Majority of the fills have a sealing layer inside of the bag to create the top and back sealing when the material overlaps. (Dudbridge 2016, p. 109)

There are two basic types of seams formed in the forming tube of VFFS machine. The first of this kind is overlap seal or film cross-section. This is where the edge of the exterior film seals with the interior film. The other type is called fold over (AKA fin) seam where the two inside edges of the film are sealed to one another. This happens when both laminated sides meet in the forming tube and pressed by the longitudinal sealing tool. (Desoki, Morimura and Hagiwara 2010, p. 31; Dudbridge 2016, pp. 109-110)

The pillow bag is among the commonly used type of packaging bags. The bag spreaders are important to create a nice looking bag. The forming shoulder, forming tube and the bag spreaders are critical factor to determine the size of the bag such as width and volume. Pillow bags are commonly found in snack packages, breakfast cereals, etc. Typical shape of pillow and block bottom bag is presented in figure 3.

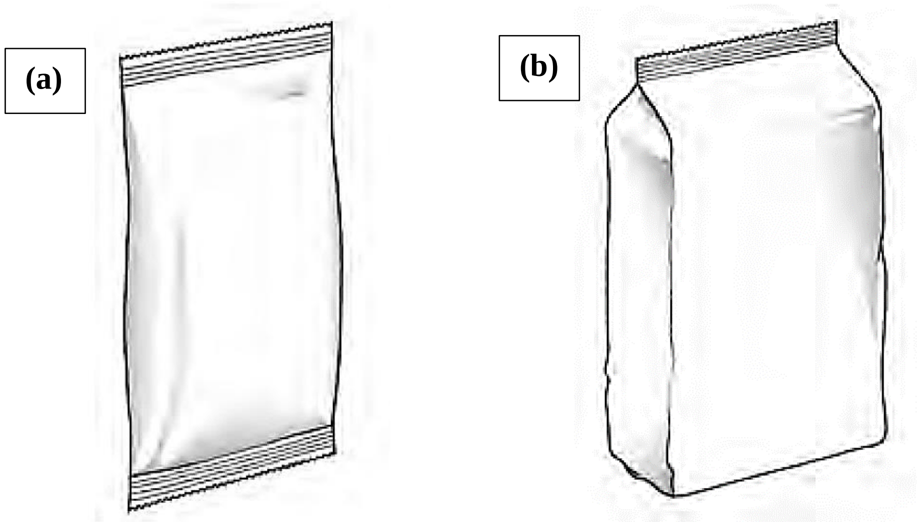


Figure 3. Typical shape of (a) pillow bag (b) block bottom bag (Guide to Vertical Form-Fill-Seal Baggers 2014, p. 9).

The block bottom bag consists of block bottom shape. This is a feature which allows the bag to stand up. At the end of the forming tube is a rectangular shaped tube instead of spreaders. It also consists of top and bottom gusset which are responsible to create a rectangular forming of the bag. Typical example of these bags is found in coffee bags and cookies.

2.4 Principles of heat sealing

Heat sealing is commonly used process for sealing flexible packaging materials. Majority of the sealing films are made of multilayer laminated polymer films. The principle of heat sealing is to attach both sides of the thermoplastic material by applying heat, pressure and dwell time. (Hishinuma 2009, pp. 21-23) Heat sealing is commonly used to join thermoplastic material which are typically less than 0.5 mm thick (Troughton 2009, p. 121). Heat sealing technology allows the formation of leak-tight containers (Emblem & Emblem 2012, p. 8) such as wraps, pouches, sealing bags, cans, bottles, films and containers made of thermoplastic (Hughes 2007, p. 695).

There are various types of heat sealing methods such as heat jaw method (also known as hot bar sealing), impulse heating, hot air blast heating, ultrasonic heating, induction current heating, electrical field loss heating and hot wire heating (Hishinuma 2009, p. 30-42). Majority of the modern food packaging industries uses heat jaw heat sealing and impulse heating method to create items such as plastic pot and tray sealing for food products (Troughton 2009, p. 121).

Jaw-bar heat sealing mechanism consists of pressure cylinders and heating block bar which compromises of temperature sensor, heater and heating pipe. The heating pipe distributes the heat by conduction from contact surface to laminate the films together. The temperature sensor continuously monitors and regulates the actual hot bar temperature to avoid fluctuations between the actual and set temperature. The heating bar temperature may vary and cause delay of the surface temperature. (Hishinuma 2009, pp. 31-32)

2.5 Heat sealing factors

The seal layer is commonly known as an adhesive layer. This layer will be attached with another film layer to complete the package. Heat sealing depends on three main parameters or processing windows and these influences the seal quality. These include sealing temperature, sealing pressure and dwell time. (Mueller et al. 1998, p. 66; Yuan et al. 2007, p. 3736) These parameters require fine control and rightly adjusted to achieve appropriate seal strength, perfect airtightness and material bond (Troughton 2009, p. 121).

Many factors could influence the quality of the heat sealing. The sealing parameters may vary depending on the material type and thicknesses, characteristics such as density, additives of the film, adhesive type etc. and the condition of the film after being sealed. (Aithani et al., 2006, p. 249) Machine design could also influence the seal by non-uniform distribution of heat transfer to the films or unequal pressure applied to the film. Therefore, the strive to achieve perfect airtightness, high quality seals to sustain the required package load and peelable seal by optimizing the processing window is among scientists' interest. (Hashimoto et al. 2005, pp. 205-206)

In packaging research and application, "easy open" or "peelable" are terms that are commonly used to refer to a seal with an acceptable seal strength which peels at the laminated film (Yuan et al. 2007, p. 3737). Having a seal that is strong enough and facilitates "easy open" packaging to the end user, is usually appreciated and well recognized by the end users (Aithani et al. 2006, p. 249), (Theller 1989, p. 66). According to Hishinuma (2009, p. 170), some of the main features of peelable seal includes the absences of delamination, reduction of heating temperature, control of polyball generation which causes pinholes and packaging failure, reduce the thickness of the adhesive layer up to 3 µm, etc.

Common application of easy open are found in candy bags, chips, cheese products or pasta packaging. To avoid heat seal failure, controlling the sealing temperature is necessary to regulate the molecular structure of adhesive layer (Hishinuma 2009, p. 10).

Up to date, there are no available literatures based on heat sealing of fiber-based packaging materials. The only available scientific research on heat sealing is limited to the laboratory work and polymer based materials such as low-density polyethylene (LLDPE) (Najarzadeh & Aiji, 2014, pp. 1594-1609; Yuan et al. 2007, pp. 773-779), high density polyethylene (HDPE) (Jones 2000, pp. 11-12), oriented polypropylene (OPP) and metallic cast polypropylene (MCPP) (Yuan et al. 2007, pp. 773-779) etc.

Packaging companies and packaging material producers restrict their technology due to the of fear technology leaks which makes this field of research very limited to open literatures. Vast number of literatures concentrate on improving and understanding the effect of heat sealing temperatures, pressure and dwell time on the quality and runnability of the seals. Additionally, discussed the effect and optimization of process window for heat sealing process in terms of seal strength of a material.

2.5.1 Sealing temperature

It is necessary to control the sealing temperature interface between the films accurately to melt the adhesive layer. Generally, in thermoplastic films, the relationship between seal strength and sealing temperature is relatively proportional as show in figure 4 below (Meka & Stehling 1994, p. 91). However, the plot may vary depending on the sealing temperature required for different materials type and thickness (Morris, 2002, p. 164).

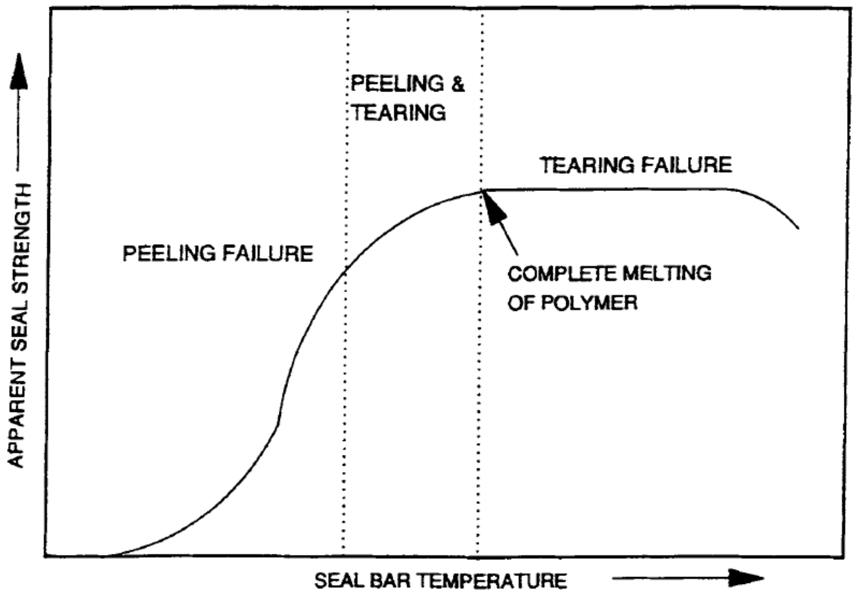


Figure 4. Relationship between seal strength and sealing temperature (Reproduced from Meka & Stehling 1994, p. 91).

In heat sealing, an adequate balance between dwell time, sealing temperature and sealing pressure must be encountered to achieve the desired and appropriate seal strength. As a rule of thumb, for the molecular chains in the sealant layer to diffuse with each other, the temperature must be high enough to activate the molecular processes (Theller 1989, p. 71). The increased temperature causes thermal expansion in the interface layer and decreases the density due to supplementary voids. With time and pressure, the surface melts crystalline polymer and creates interdiffusion of chains which gradually leads to recrystallization of molecules. (Stehling & Meka, 1994, pp. 105-107; Theller 1989, p. 72).

As a summary, from industrial practices, high sealing temperature would require less dwell time to seal the package and vice versa. However, precautions must be taken not to overheat the material. In packaging industries, tooling profiles are used to improve and optimize the energy consumption produced by the machine. (Theller 1989, p. 72).

2.5.1 Dwell time

Dwell time is the second controllable factor to heat the adhesive layer of the packaging films. In short, it is the time required to heat seal the material to create molecular entanglement between the adhesive layer and interfacial zone. In commercial application, when heat is applied to the material, the sealing process is usually for 1s or less. (Stehling & Meka, 1994, pp. 105-106)

In packaging industries, VFFS machines are generally operated at high production speed, therefore, it is important to have least dwelling time possible. Dwelling time is precisely adjusted to control the time needed to apply heat and pressure. As part of production and economic optimization, it is important to seal the material as fast as possible in packaging lines (Najarzadeh & Aiji 2014, p. 1953).

Study done by Najarzadeh and Aiji (2014) and Theller (1989) concluded that increasing dwell time improves the seal strength. This is because diffusion in any system is time-dependent process. There would be more time for the chain molecules to transform from crystalline to molten film and until it recrystallizes after sealing.

2.5.2 Sealing pressure

Sealing pressure is used to bond or bring the films together and hold the material to form the seal. Among all the three heat sealing parameters, pressure is the least significant factor that influences the seal strength (Meka & Stehling 1994, p. 90). The seal strength is said to be directly proportional to the sealing pressure. The higher the sealing pressure, the higher the seal strength. However, majority of the researchers concluded that sealing pressure has no effect after certain pressure range ((Meka & Stehling 1994, 90; Theller 1989, p. 72).

At very high pressure range, the seal strength is relatively the same for the thermoplastic materials. However, there are certain materials with low elastic modulus behaves differently. These materials require high pressure. (Theller 1989, p. 72). Comparing dwell time and pressure effects, variation in dwell time had a larger effect than pressure on seal initiation temperature and plateau temperature broadness (Najarzadeh and Aiji, 2014).

Yuan et al. (2007, p. 777) reported in her study that it is unlikely to have any seal below 1 bar. In this study with OPP/MCPP materials, a noticeable seal was first observed at 1.25 bar. Gradually, at a higher sealing pressure, there was no significant differences in the seal strength. The figure 5 below summarizes this context. This confirms that the sealing pressure has no significant effect on seal strength as similarly stated by previous pioneer researchers Meka & Stehling (1994) and Theller (1989).

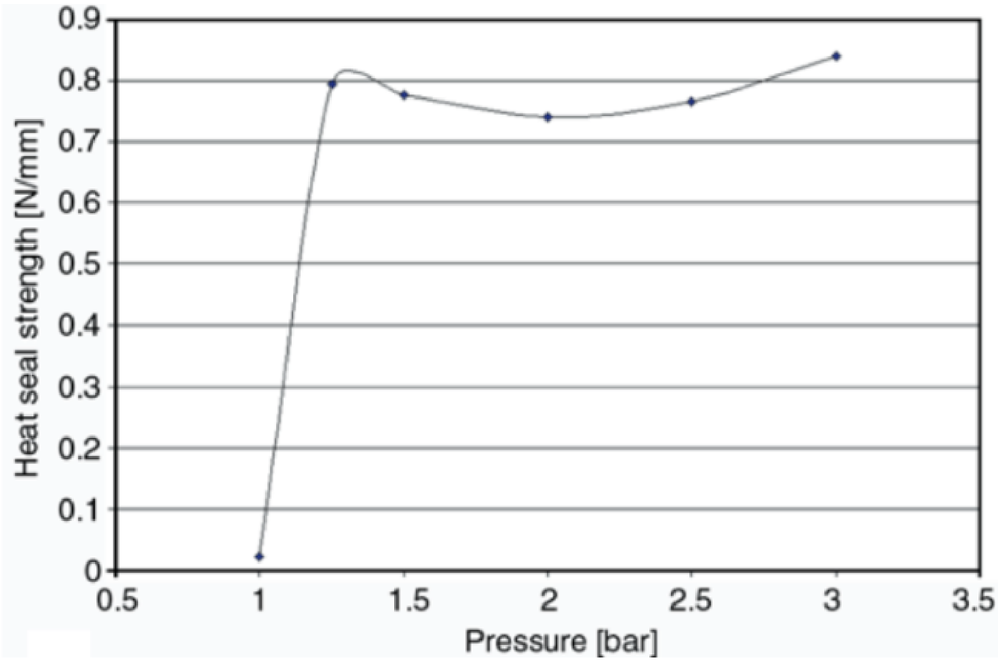


Figure 5. Pressure seal strength relationship (Reproduced from Yuan et al. 2007, p. 777).

2.6 Principles of hot tack

Hot Tack is the strength of the heat seal to withstand stress while the seal is still hot. Hot tack performance is important parameter in majority of food packaging production. Hot tack property depends from one material to another. The hot tack strength window is very broad and depends on the material. Some materials such as LDPE has a wider sealing temperature range than LLDPE. (Bamps et al. 2019, pp. 339-343)

In VFFS, hot tack is a critical property. The principle of VFFS is to disperse the product through dispensing dozer with the help of gravity directly after the opening of the hot jaws. (Bamps et al. 2019, p. 339) This would exert high force on the seam which could open-up the unsolidified seam. The adhesive layer should solidify immediately after the closure of the jaws.

3 RESEARCH METHODOLOGY

The objective of this thesis was to evaluate the evaluate and optimize the VFFS machine for flexible packaging papers and to compare them with the thermoplastic polymer materials. The following chapter provides an overview of the testing procedure. The materials and equipment along with processing parameters used are described in detail.

3.1 Overview of experimental procedure

An overview of the flow chart presented in figure 6. Mainly, the experimental procedure was divided in two main stages where the first stage was to conduct preliminary tests and second stage involves the evaluations in order to suggest several improvements for optimizing performance of the VFFS machine.

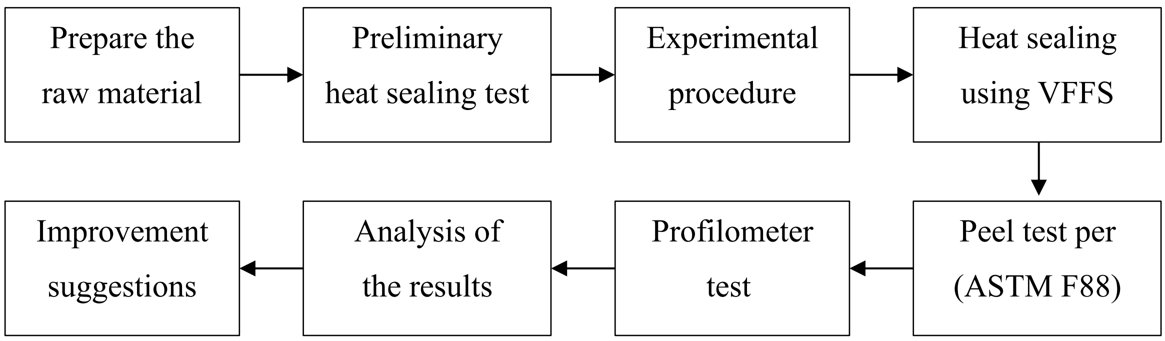


Figure 6. Overview of experimental procedure.

The process begins with the preparation of raw materials by precisely cutting the rolls into sheets of 240mm x 75mm. The raw materials are of two types, thermoplastic polymers and flexible packaging papers which are explained in detail in section 3.2. These films are used to conduct preliminary heat sealing test with the laboratory heat sealer as a preparation to conduct heat sealing using VFFS machine, further discussed in section 3.3.

3.2 Materials used

The material samples used in present study were of two different kinds, flexible packaging material and thermoplastic polymer. Each of these materials are of different film thicknesses, grammages and adhesive layers. The technical specification of the materials is presented in detail in table 1.

Table 1. *Technical specifications of flexible packaging papers and thermoplastic polymer.*

	Fiber 85	Fiber 120	Plastic 15-35	Plastic 50
Polymer coated paper	Yes	Yes	NA	NA
Thickness, µm	78	125	52 ± 6%	-
Grammage, g/m^2	85	120	35	50
Base paper	70	90	NA	NA
Layer PE adhesion, g/m^2	15	30	0.3	-
Moisture, %	4.3	4.3	7 ± 10%	-

NA: not applicable.

The materials are named according to their material type and grammages. Both of these materials have an adhesive sealing layer on the inside of the film roll. The two fiber-based material are based on polymer coated flexible packaging paper. The pigment coating is on the top and the polyethylene coating on inside. The two plastic films used were of commercial OPP/PE materials. The Plastic 15-35 is a laminate film with grammage 15 OPP + 35 grammage PE. The Plastic 50 is an OPP film with grammage 50. The other detailed specifications for Plastic 50 remain unknown.

<u>The equipment used for sample making are as follows:</u>

3.3 Gravimetric moisture analyzer

It is essential to measure the moisture content to control the quality of the fiber-based materials. Moisture analyzers utilizes a method known as Loss of Drying (LOD). The sample was first placed in the moisture analyzer and weighed. The device heats up the material until all the moisture evaporates and weighs again. The initial weight was subtracted from the final weight to achieve the final moisture content of the material.

To verify the moisture content of fiber-based material, three grams of Fiber 85 and Fiber 120 are placed in PMB moisture analyzer shown figure 7. The units for the moisture content are measured in %M. Fiber-based materials, Fiber 85 and Fiber 120, were kept in the humidity chamber at 80 % relative humidity (RH), for at least 24 hours before usage. This was necessary to obtain the required moisture level before operation.

Figure 7. PMB moisture analyzer – ADAM.

3.4 Heat sealing apparatus

Initially, the RDM HSB-1 Laboratory Heat Sealer in figure 8 was used to investigate the appropriate preliminary heat seal, dwell time and sealing temperature, for both fiber-based and thermoplastic polymer material. This step was crucial to determine range of possible heat sealing processing window for both materials. The following device consists of flat sealing bar which produces maximum seal of 300 mm long and 25 mm wide. The heat sealing variables (dwell time, sealing temperature and sealing pressure) can be controlled individually in order to obtain an optimum or required seal strength. (Neal, 2020)

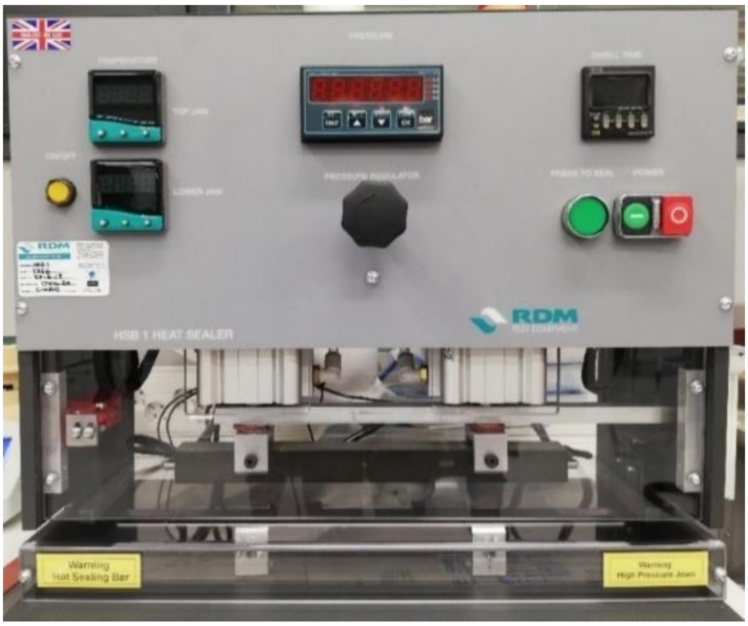


Figure 8. RDM HSB-1 laboratory heat sealer.

To investigate the appropriate sealing parameters for the preliminary test, seal samples were precisely cut to 240 mm x 75 mm. As the majority of the published articles stated that sealing pressure does not have major effect on the seal strength, it was set to maximum operating pressure at 5 bars for all samples resulting in surface pressure of 0.42 bars. The samples were examined in range of different sealing temperatures and dwell time. It was recognized that the optimum sealing temperature ranges from 100 to 220 °C for fiber-based material and 100 to 150 °C for thermoplastic material. The minimum required dwell time was recorded to be 0.4 s, therefore, applicable dwell time should range between 0.5 to 2 s.

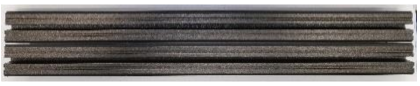
The VFFS GKS-Compack CP350 Plus shown in figure 9 is used as the main experimental equipment for this research. It consists of five different sealing tool profiles and three different sized forming shoulders. However, only three different sealing tool profiles and medium sized shoulder will be used for this experiment.

Figure 9. VFFS GSK-Compack CP350 Plus.

The machine can produce two different forms of bags, namely pillow bag and block bottom bag. On average, 15 pillow bags with 200 mm length are produced with different sealing tools. The film transport speed setting ranges from 0 to 10 where 8 was selected as constant speed parameter. The actual speed would have to be measured. The acceleration and deceleration time of the film transport was set to 200 ms and 100 ms, respectively. The seal jaws are kept at constant pressure 6 bars resulting in surface pressure of 0.31 bars for Tool 1, 0.7 bars for Tool 2 and 0.84 bars for Tool 3 with 140 mm bag width. The longitudinal length seal was set to 5 bars resulting in surface pressure of 0.65 bars.

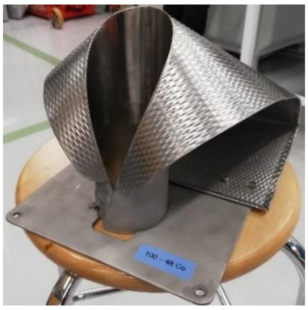
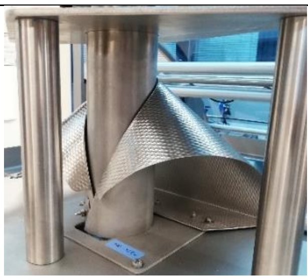
Table 2 presents the sealing tool profiles used in this experiment. Tool 4 has been omitted from the experiment because it had similar surface profile at Tool 3. Tool 5 gave inaccurate surface temperature readings which is further discussed in chapter 4 under section 4.2.1.

Table 2. Different types of sealing tool profiles.

Sealing tool profile name	Tool profile types	Seal size and description of the tool profile	Used
Tool 1		11mm Serrated profile	Yes
Tool 2		3 + 4mm Two flat surfaces	Yes
Tool 3		5mm Flat surface	Yes
Tool 4		4mm Flat surface	No
Tool 5		11mm Flat surface	No

The table 3 presents different forming shoulders which are compatible with the VFFS GSK-Compack CP350 Plus machine.

Table 3. Different types of forming shoulders.

Name	Forming shoulders types	Size	Used and reasonings
Optimized small shoulder		100-48Co	No, because the shoulder does not have accessories for making block bottom bags. The produced pillow bags will be used to examine the surface roughness. However, the material forms without any issues.
Medium sized shoulder		140-72Co	Yes, because the fiber-based material forms smoothly over the forming shoulder with not wreckages of the material seen.
Large shoulder		180-155Co	No, because of the sharp fillet at the end of the forming shoulder and near the tube.

Each material was heat sealed with a sealing temperature ranging from 100 - 140 °C with an increment of 10 °C and dwell time of 0.5 - 2.0 s with an increment of 0.5 s. The final sealing parameters used for VFFS machine is presented in table 4. All the parameter setting was saved in the VFFS program for future use.

Table 4. Experimental parameters to be used with VFFS machine.

VFFS GKS Program No.*	Heat Sealing Temperature (°C)	Dwell Time (s)	Seal Jaws (Bars)	Length Seal (Bars)
16	100	0.5	6	5
17	110			
18	120			
19	130			
20	140			
21	100	1.0	6	5
22	110			
23	120			
24	130			
25	140			
26	100	1.5	6	5
27	110			
28	120			
29	130			
30	140			
31	100	2.0	6	5
32	110			
33	120			
34	130			
35	140			

No*: the parameters are saved accordingly in the GKS system.

3.5 Infrared thermal gun

Infrared thermometer gun is a non-contact temperature measuring device. The following device emits infrared energy to an aimed target which results an immediate display of the temperature. To achieve an accurate temperature reading, the distance to spot ratio is 12:1. The device will be used to measure the temperature of heat bar sealing and the temperatures at the jaws of VFFS machine. As a common practice and accuracy, three temperatures measurements will be taken on a same area on three different locations to achieve an average temperature.

3.6 Peel testing machine and sample preparation

After the pillow bags were produced with the VFFS machine, they were carefully stored in plastic bags at room temperature before being tested with Shimadzu AGS-1kNX using 1 kN load cell as shown in figure 10. In practice, the package products are kept in a storage before being used by consumers. Therefore, the seal test was conducted at least 48 hours after the production to ensure that the adhesive seal was stabilized as recommended by ASTM F88.

Figure 10. Shimadzu AGS-1kNX peeling test device

To examine the seal strength of the sealing tool profiles, only the top and bottom seam are assessed. Three pillow bags are cut in strips of fin seal with 25 mm in width and 35 mm in length to fit in the Shimadzu grips. T-peel method with 90° angle was used to separate the adhered seals as shown in figure 11. The number of sampling was fixed to six. This can be considered low, however it was enough to eliminate the bias results. The sealed specimens are placed approximately equidistant and parallel to the clamp in the pulling direction. The peel test was conducted as per the guidelines of ASTM F88 (ASTM F88, 2020). Initially, the specimen was pretested at a constant rate (*v)* of 50 mm/min to the point it reached 0.2 N to remove slack from the sample. The machine then pulls at constant rate of 300 mm/min until 2 % break detection.

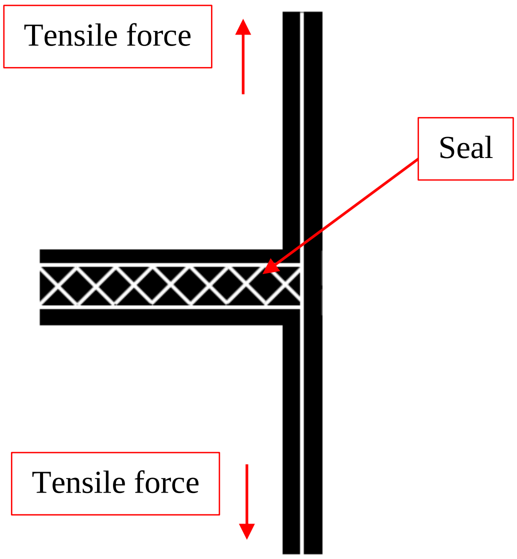


Figure 11. T-peel method with 90° pulling direction.

3.7 Profilometer

Profilometer is a contactless 3D macroscopic device that is used to measure the profile's topology. The device provides roughness quantity in form of computed topography from the selected surface area. For this experiment, Keyence VR 3200 shown in figure 12 was used. This device measures the roughness of the surface by emitting white light of an LED source on a selected surface area. The reflected light is collected and analyzed with spectrometer. (Nouira et al 2014, p5)

Figure 12. Keyence VR 3200

For this experiment, profilometer was used to measure the roughness of pillow bags using two forming shoulders, optimized small shoulder and medium sized shoulder, which are compared with the original film. The two fiber-based materials, Fiber 85 and Fiber 120 are compared to investigate the effect angles of forming shoulders with roughness.

The samples were measured with 12x magnification and with 50 mm x 100 mm of scanned surface area. Three bags were examined, and the average values of Ra (average) and Rz (highest) were noted from the profilometer. These values are useful to understand the wrinkles that formed by the forming shoulders.

4 RESULTS AND DISCUSSION

4.1 Moisture content

Moisture content of the fiber-based materials were examined before heat sealing test. From the manufacture catalogue, the moisture content was said to be 4.3% for both Fiber 85 and Fiber 120. The test was conducted by adding 3 grams of each material, placed in PMB moisture analyzer and heated at a gradual rate. It took 3:30 minutes for the moisture content to evaporate from both materials.

The results obtained from the device showed that the two materials did not have same moisture content. The Fiber 85 had 11 % lower moisture content than the Fiber 120. The thicker material had the ability to store more moisture content than the thinner material.

Table 5 shows the lost moisture content from the fiber-based materials. The thicker material, Fiber 120, was found to have higher moisture content because it can trap more moisture within the film. However, it was recognized that there were no observable improvements in runnability of the materials over the forming shoulders and tubes. Secondly, only the top layers of the reel were in contact with the moisture content in the humidity chamber. After running several bags, the reel already reached the dried side of the film.

Table 5. Moisture content in fiber based material.

Material	Manufacturer value moisture content [%M]	Measured moisture content [%M]	Difference %
Fiber 85	4,3	2,66	38
Fiber 120	4,3	3,14	27

4.2 Effect of VFFS tools

4.2.1 Sealing tool pressure calculation

Table 6 presents the RDM laboratory heat sealer, VFFS length and horizontal sealing jaws. As mentioned in Chapter 3, medium sized shoulder with 140 mm width was used and the surface pressure area was calculated accordingly. The forces presented in the table are based on data sheet from the manufacturer.

The adjustment of heat sealing parameters in Chapter 3 were based on the results from the RDM laboratory heat sealer. The RDM heat sealer cannot be used to guarantee same results unless the surface pressure is consistent to other test devices. The appropriate pressure calibration between the two devices is necessary to result secure adhesion on the sealant.

Table 6. Surface pressure calculations

	Laboratory heat sealer	VFFS length seal	VFFS horizontal sealing tools				
Tool Name	Heat bar sealer	Longitudinal length sealer	Tool 1	Tool 2	Tool 3	Tool 4	Tool 5
Force (N)	2587,5	1256	2356	2356	2356	2356	2356
Surface area (mm^2)	6096	1920	7616	3360	2800	2240	6160
Pressure (MPa)	0.42	0.65	0.31	0.70	0.84	1.05	0.38

4.2.1 Sealing tool temperature verification

To verify the accuracy of the temperatures throughout the sealing tool, temperatures were set to 130 °C and measured with infrared thermometer gun. It was realized that the sealing jaws, Tool 1 to Tool 4, gave accurate readings ± 2 % across the bar, with average temperatures ranging from 132.5 to 127.4 °C. The highest temperature was recorded at the origin of the heat source on the left side of the sealing tool. Figure 13 presents the location of the heating source in the VFFS machine.

The different range of temperatures recorded in the heat bar follows the principles of heat transfer. With this fact, it is easy to understand that it is difficult to keep the setting temperature consistent across the bar. The heat conductivity of the heating jaws depends on the location of the heat source.

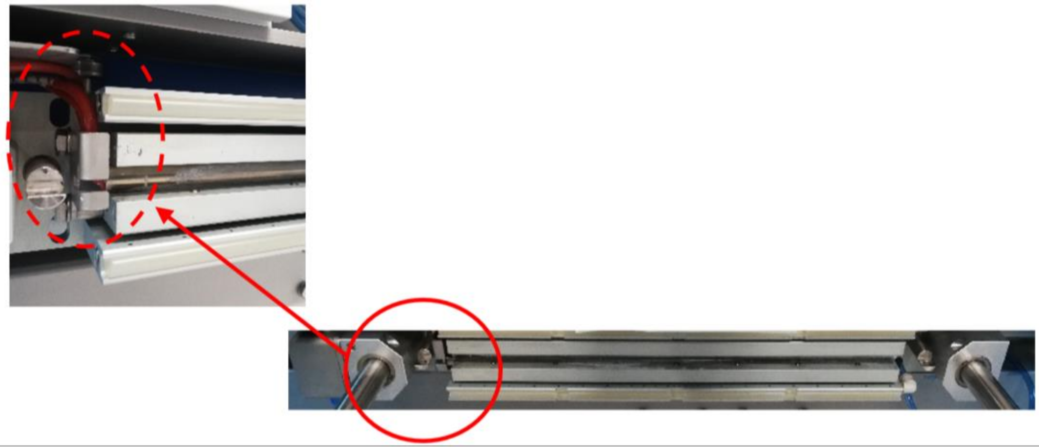


Figure 13. Temperature heat source from VFFS machine.

Tool 5 had temperature variance of up to 15 %, recording about 10-20 °C below the setting temperature. The thick polytetrafluoroethylene (PTFE) coating in the back of the sealing tool is thought to be reason behind inaccurate sealing temperatures. PTFE materials are widely used for electrical applications as wire insulators. For this explanation, the coating acted as an insulating material leading to a reduction of surface temperature at the surface of the jaws.

4.2.2 VFFS machine pneumatic settings

Forming shoulder is responsible for adjusting the edges of the film web to the forming tube. The edges are overlapped, and heat sealed in the tube. However, in this experiment, the forming shoulder was a crucial element. The movement of the film over the shoulder corresponds with the adjustment of the film tension from the pneumatic control unit. This unit is responsible for pressure settings for the VFFS components including, seal jaws, length seal, transport belt, film brake, gusset, etc. and can be controlled individually.

Film tension has a huge impact on the runnability of the materials. Initially, during production of the pillow bags trials, it was recognized that the film over the forming shoulder tended to shift or wander towards the right or left. This phenomenon was observed in both fiber-based and thermoplastic materials. At first, the film tension was set to zero bars leading to unbalanced tightness over the film.

The figure 14 presents the wandering of the film over the forming shoulder. It was identified that lower film tension leads to the movement of the film over the shoulder towards the right and vice versa. The film tension must be regulated and controlled precisely, otherwise it may lead in breakage of the material around the shoulder's fillet or near the belt transport system.

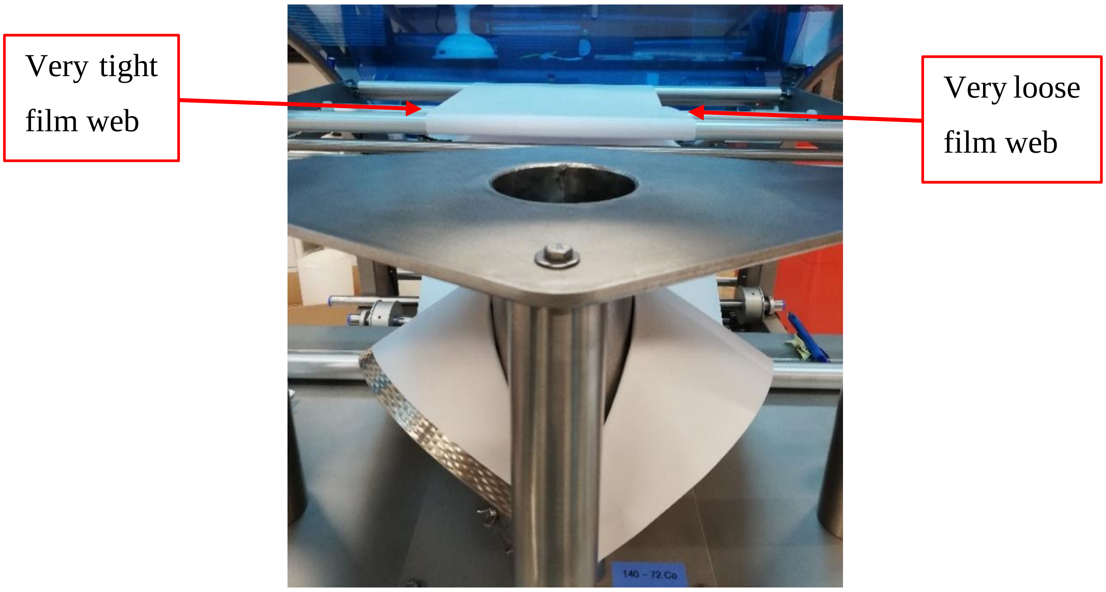


Figure 14. Wandering of the film over the forming shoulder.

Each material behaves differently due to its material properties. Material elasticity, thickness and friction significantly affects runnability of the film. Each material requires appropriate pressure adjustments and calibrations to make sure the film overlaps in the forming tube. The VFFS machine consists of various pressure control settings for different components. The film tensioning system is operated by control valves. Table 7 summarizes the pneumatic settings required for the VFFS components. These settings are essential to improve the runnability of the different materials used. Majority of the pressure adjustments was conducted on the belt transport mechanism and film tension, whereas the rest was kept constant.

Table 7. VFFS pneumatic settings for different materials.

VFFS machine pneumatic settings		Material types			
		Fiber 85	Fiber 120	Plastic 15-35	Plastic 50
VFFS components	Seal jaws	6 bars	6 bars	6 bars	6 bars
	Length seal	5 bars	5 bars	5 bars	5 bars
	Belt transport	5 bars	5 bars	5 bars	6 bars
	Film brake	3 bars	3 bars	3 bars	3 bars
	Film tension	2 bars	1 bar	0.5 bars	4 bars
	Gusset	6 bars	6 bars	6 bars	6 bars

It was concluded that each material requires appropriate pressure regulations due to different material properties of the films. The pneumatic unit consists of various pressure control settings for different parts of VFFS system. To improve the runnability of the material, belt transport and film tension requires constant pressure calibration depending on the material.

The Plastic 50 and Fiber 85 operated with a film tension of 4 (180.9 N) and 2 (90.5 N) bars, respectively. These materials showed excellent drive over the forming shoulder and through the tube. The Plastic 15-35 showed slipping phenomena when the web tension was set to zero and high stress leading to breakage at 1 bar. It is possible the Plastic 15-35 inherent properties such high COP, static and film distortion which are thought to be the negative aspects of this material (Clark & Wagner 2002, p. 146). Similar behavior was noted for Fiber 120 which consists of higher thickness.

4.3 Evaluation of seal strength

Tensile test was carried out to examine the peel strength of each material with different tools. This provide us an information on the mechanical properties of the sealed specimen and processing window. Load displacements curves for each sealing tool are compared with different dwell time and materials. The highest value obtained in the load displacement graph is defined as the ultimate seal strength. The results and respective graphs presented are the average of six that were pulled at 90° angle. The failure modes of each material with its corresponding sealing tool was examined carefully.

4.3.1 Sealing jaw Tool 1

The Tool 1 has serrated profile which consists of 8 ribs. This tool design has a unique property with variety of possible applications. For example, the horizontal parallel ribs exert high surface pressure which creates a gas tight seal. Three materials, Fiber 85, Fiber 120 and Plastic 15-35 successfully sealed at 100 to 140 °C. Whereas the Plastic 50 had no sealing until higher temperatures (above 120 °C) due to high melting temperature for OPP50.

At 100 °C, Fiber 85 and 120 experienced peelable seal with an easy peel phenomenon. The heat seal faced no failure in the laminated structure as shown in figure 15. At this sealing temperature, the strength of the seal is lower than the strength of the adhesive sealant. This concludes the sealing temperature at 100 °C is lower than the melting point of the adhesive sealant. (Yuan & Hassan 2007, p.775)

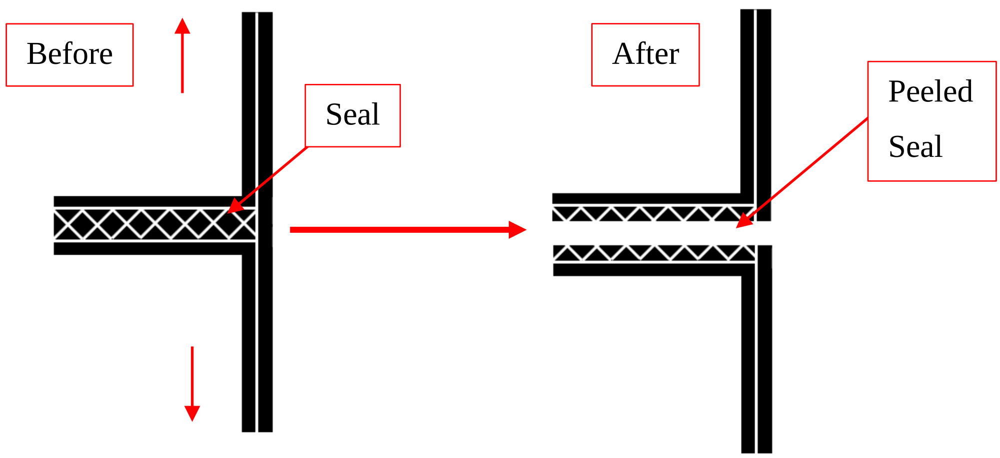


Figure 15. Easy peel phenomena seen at 100 °C sealing temperature.

Above 110 °C, all the fiber-based materials delaminated. The heat sealant is mangled and separated from sealing layer due to the high stress concentration caused by the serrated tool profile. Figure 16 demonstrates how the laminated heat seal separated from the sealing. The seal strength substantially enhanced with increase in temperatures and dwell time.

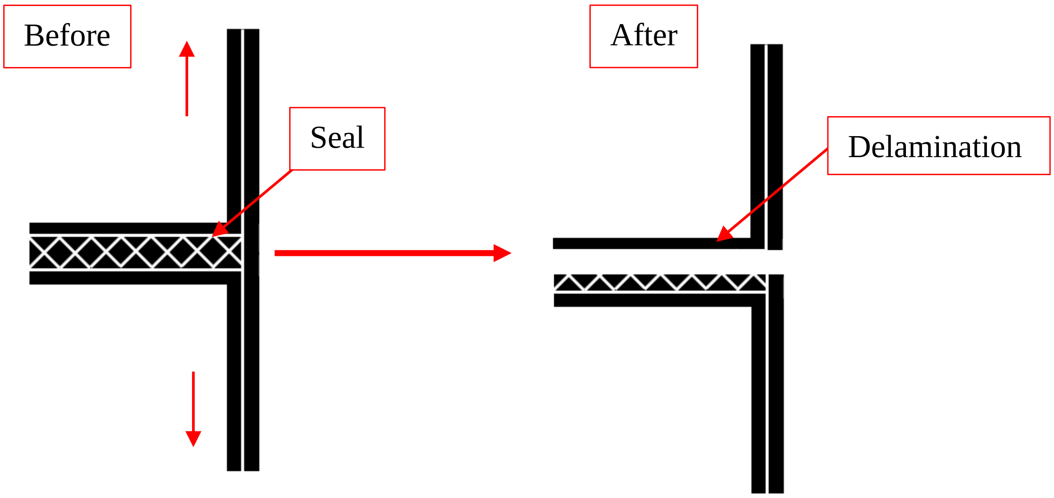


Figure 16. Delamination of fiber-based material above 110 °C sealing temperature.

The load-displacement graph in figure 17 (a &b presents the fiber-based materials sealed at sealing temperature 100 °C and 0.5s dwell time. These graphs clearly present significant fluctuations after the first peel. These number of sharp fluctuating spikes are a result of serrated tool profile. The Fiber 120 has a higher seal strength than Fiber 85. This is the result of thicker adhesive layer found in Fiber 120. Thicker adhesive layer has higher interdiffusion of polymer chains. Based on this principle, the final seam tends to have stronger re-crystallization and entanglement of polymers upon cooling (Najarzadeh & Ajji 2014, 1593).

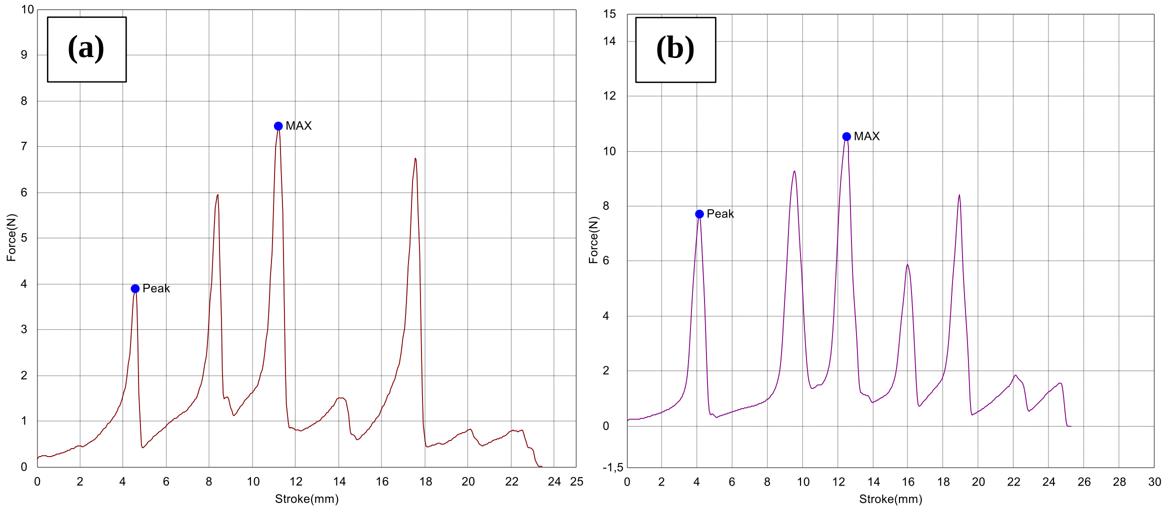


Figure 17. Force-displacement graph for dwell time 0.5 s and sealing temperature 100 °C for (a) Fiber 85 and (b) Fiber 120 using Tool 1.

The Plastic 15-35 experienced a similar fluctuation with poor sealing quality at 100 °C samples. The average sealing strength was about 0.35 N and all these samples behaved similarly regardless of the dwell time. At 110 °C, the sealed samples showed an easy peel with an enhanced seal strength of about 10 N. At this stage the polymer molecules are thought to have interdiffusion of chains across each other. Above 120 °C, the material breaks at the edge of the laminated film as demonstrated figure 18. The laminated film failed to tear because the seal strength exceeds the laminated bond.

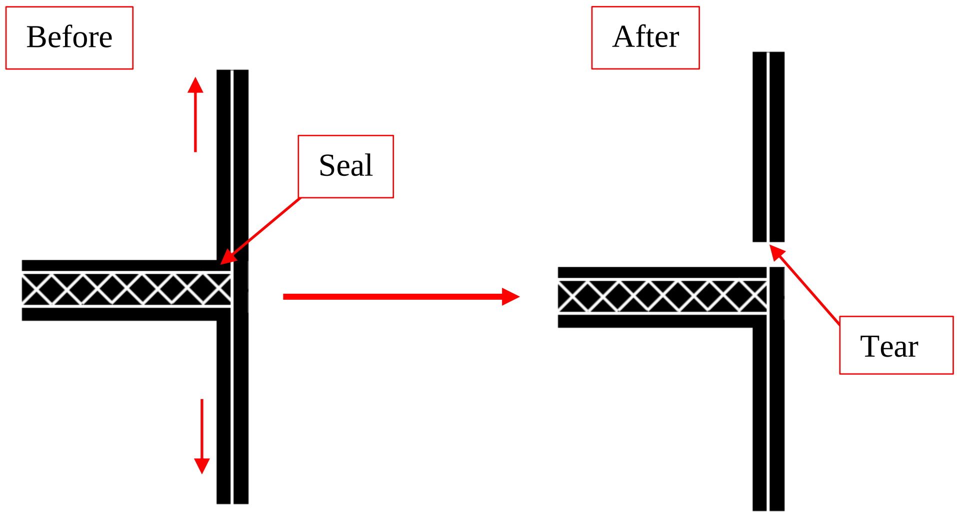


Figure 18. Breakage of laminated film for Plastic 15-35 above 120 °C sealing temperature.

4.3.2 Sealing jaw Tool 2

The Tool 2 consists of 2 sealing surface areas with different widths 3 and 4 mm. The two sealing layers provides additional sealing security for the produced bags. From the pressure calculation presented in table 6, Tool 2 has higher surface pressure than Tool 1 and RDM heat sealer. However, from the experimental trials using VFFS, it was realized that none of the materials sealed at 100 °C for horizontal seam with Tools 2 even though they have sealed with the RDM laboratory. This section requires further investigation to understand how the geometry of the sealing profile affects the seal performance.

All materials, except Plastic 50, sealed at 110 °C regardless of dwell times. At this sealing temperature, it was observed that the Fiber 85 and Plastic 15-35 did not experience easy peel and have completely delaminated because the laminated molecular structure is relatively stronger than the heat seal. However, with Fiber 120, the sample experienced an easy peel because not all the adhesive material reached the melting point and recrystallization phase (Najarzadeh & Ajji 2014, 1594).

As similarly stated in section 4.3.2, Plastic 50 requires higher sealing temperature to create the adhesion of polymer molecules. Plastic 50 was found to seal at temperatures 130 °C and above. The material peeled off clearly from the laminated layer as shown in figure 15. No delamination was observed in the heat bond at sealing temperatures 130 - 140 °C. Similarly, this because the seal strength is lower than the laminated seal.

From the load displacement graphs for fiber-based materials, we can identify a unique relationship between the two thicknesses, Fiber 85 and 120, sealed at 110 °C and 130 °C sealing temperature with 1.5 s dwell time. First of all, majority of the heat sealed samples with Tool 2 relatively had seal strength of about 8 N for Fiber 85 and 10 N for Fiber 120. Secondly at sealing temperature 110 °C, the graph showed two fluctuating peaks whereas the first peak is always lower than the second peak as presented in figure 19 (a-b). These peaks are relevant to the 2 sealing surface areas available in Tool 2. At higher temperatures, the material has experienced full delamination with single sharp peak as presented in figure 19 (c-d). There were no distinguishable differences in sealing layers because all the adhesive layer has reached a molten phase. Due to high temperatures, it is possible that the two adhesive layers experienced intermolecular interaction to form one complete lamination.

The load displacement graphs for Plastic 15-35 presented figure 19 sealed at 1.5s dwell time with a sealing temperature at (a) 110 °C and (b) 130 °C using Tool 2. Figure 20 (a) has two fluctuating peaks with an average seal strength of about 22.5 N. The first peak was lower than the second peak by about 5 N. This is because the second surface area has higher sealing surface pressure due to the geometry of Tool 2. At higher temperatures, above 120 °C shown in figure 20 (b), the graph increased sharply with no transition between the two sealing layers. The increase of temperature resulted in bonding molecules to be stressed and adhering the two surface areas into one layer (Hishinuma 2009, p. 156). The high tension force lead to breaking of the laminated film at the edge of the seal as shown in figure 18. This concludes that the strength of the laminated seal is stronger than material structure.

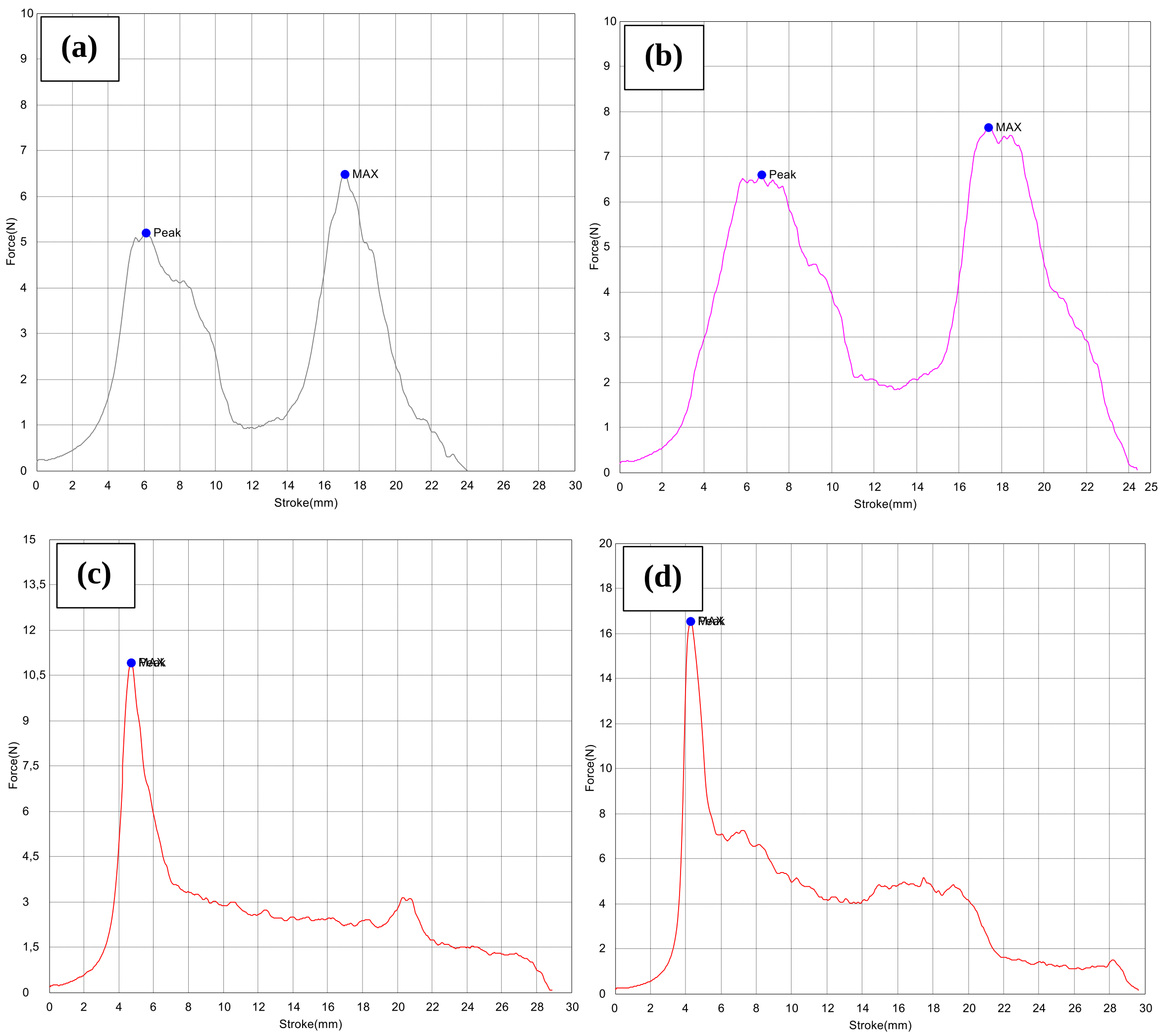


Figure 19. Force-displacement graph for Fiber 85, dwell time 1.5 s and sealing temperature (a) 110 °C and (c) 130 °C and Fiber 120 at (b) 110 °C and (d) 130 °C using Tool 2.

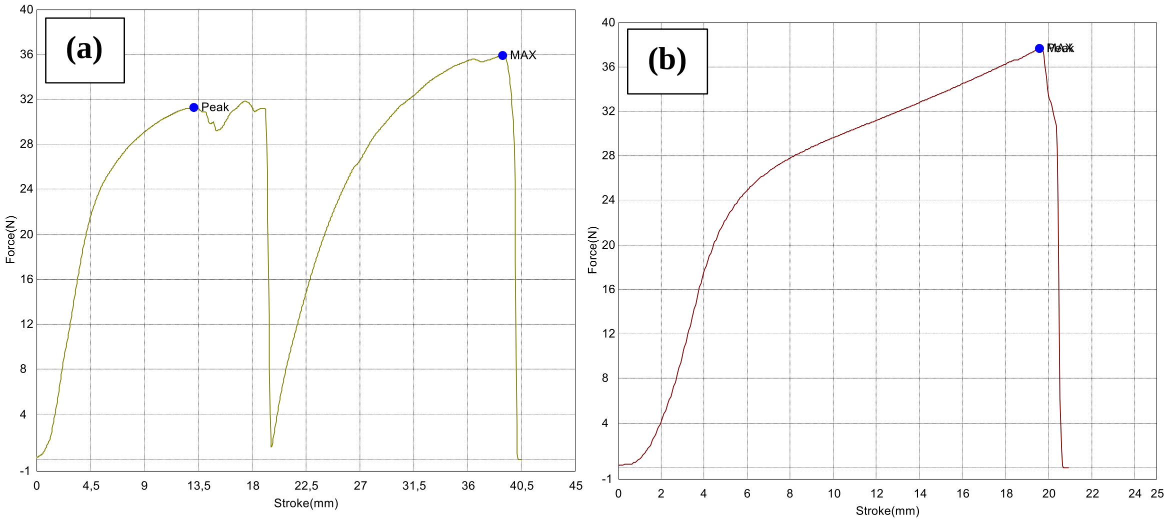


Figure 20. Force-displacement graph for Plastic 15-35 at dwell time 1.5 s and sealing temperature (a) 110 °C and (b) 130 °C using Tool 2

4.3.3 Sealing jaw Tool 3

The Tool 3 is a form single flat bar with 5 mm width. From table 6, this tool had the highest surface pressure. The thin sealing layer provides additional seal strength and storage for the products in a bag. Both fiber-based and Plastic 15-35 material had difficulties sealing at 100 °C. Whereas the Plastic 50 only sealed at sealing temperature 130°C and above.

Tool 3 behaved similarly to Tool 2. From the load displacement graph in figure 21, Fiber 85 and 120 have been sealed at 110 °C and 130 °C sealing temperature with 0.5s dwell time. The material exhibited a uniform peel seal until 6 mm loading distance (stroke). Minor fluctuations occurred after the first peak which are caused by air bubbles and foams found the laminated layer (Hishinuma 2009, p. 105). The fiber-based materials experienced an easy peel with minor delamination of the sealant. At 130 °C sealing temperature, the fiber-based material exhibited a sharp peak and with larger delamination in the laminated film as presented in figure 15. This could be because of the sealant layer is stronger than the material causing a molecular entanglement in the interfacial zone (Yuan & Hassan 2007, p.775).

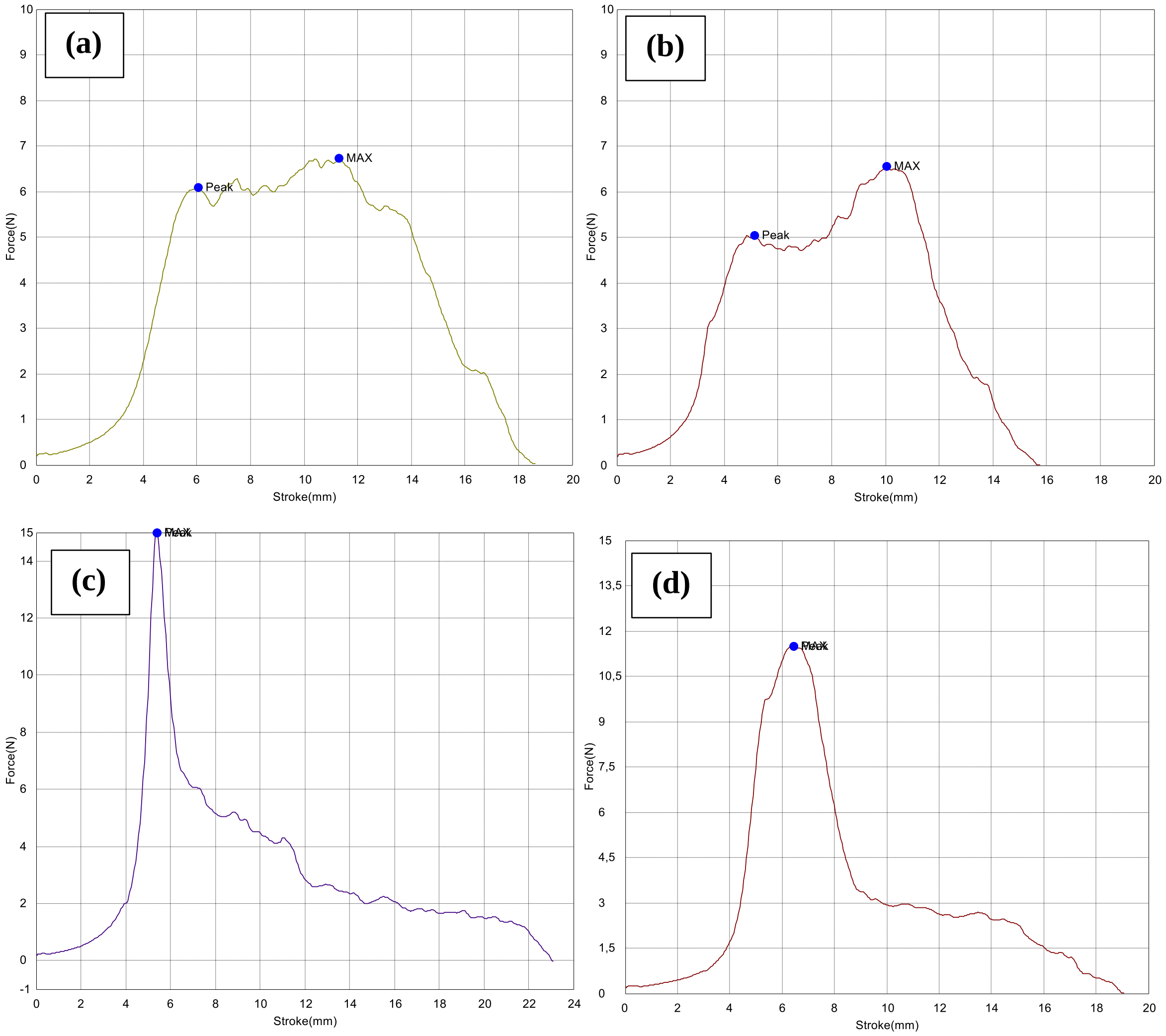


Figure 21. Fiber 85 sealed at (a) 110 °C and (c) 130 °C sealing temperature and Fiber 120 sealed at (b) 110 °C and (d) 130 °C sealing temperature with 0.5 s dwell time.

Figure 22 presents load displacement graph of the Plastic 15-35 which has sealant layer teared apart from each other with difficulties. The sealant polymers are fused with one another causing interdiffusion of chains across the sealant (Hishinuma 2009, p. 105). The material breaks at the edge of the heat seal because the strength of the laminate layer is stronger than the material as shown in figure 18

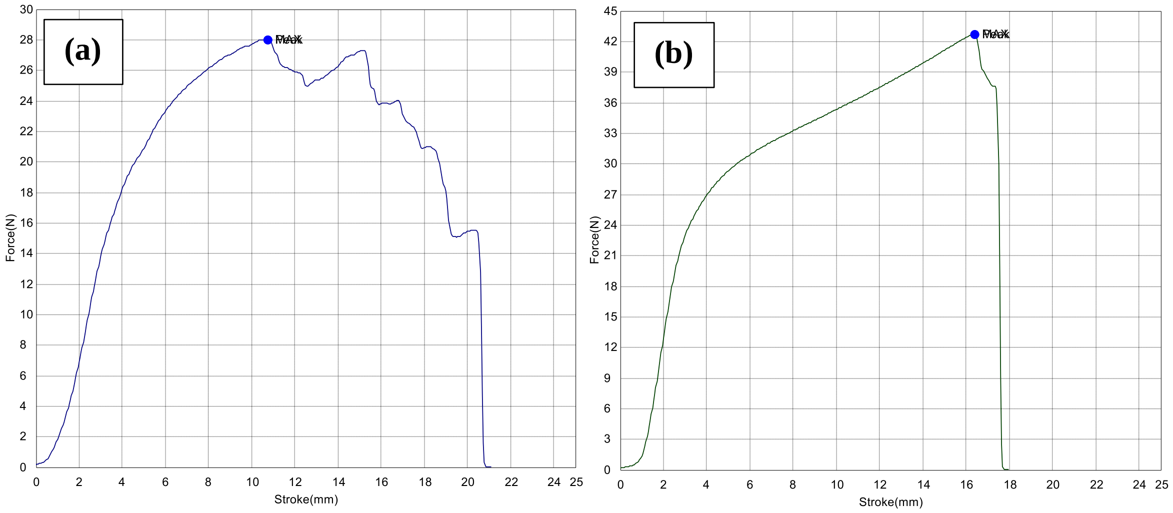


Figure 22. Plastic 15-35 sealed at (a) 110 °C and (b) 130 °C sealing temperature with 0.5 s dwell time.

Among all studied materials for Tool 3, the Plastic 50 exhibited the unusual behavior as two fluctuating peaks were observed. From the load displacement graph in figure 23, these two fluctuating peaks are thought to represent the start and the end of the seal. The sample has easy peeled with no delamination observed. Apart from the two peaks, this sample reported the lowest seal strength with an average of 0.5 N. As, the OPP50 is of thicker material, it requires higher sealing temperatures.

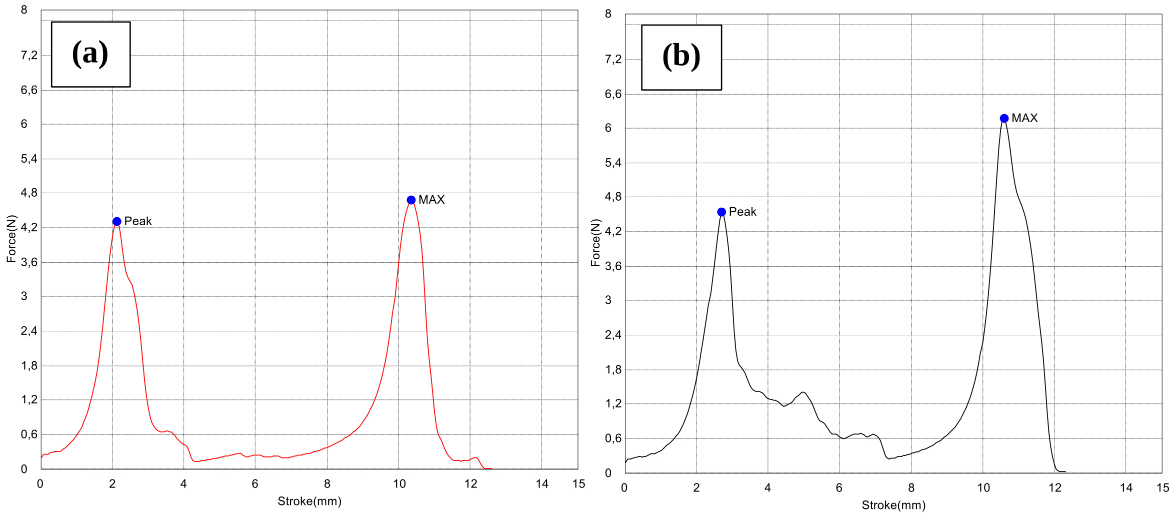


Figure 23. Plastic 50 sealed at (a) 130 °C and (b) 140 °C sealing temperature with 0.5 s dwell time.

4.4 VFFS processing windows

To determine the processing window for the VFFS machine, the effect of sealing temperature and dwell time while keeping the pressure constant is conducted. This is an important validation for design optimization using different sealing tool profiles and materials. All the contour and 3D plots presented in this section were drawn using Surfer® (Golden Software, LLC). The contour plots present sealing temperature varied from 100 to 140 °C in steps of 2 °C and dwell time varied from 0.5 to 2s in steps of 0.5s. The seal strength is presented in a form of color bar ranging from purple (lowest) to dark red (highest).

The figure 24 presents fiber-based and thermoplastic polymer contour and 3D plot using Tool 1 sealing profile. Considering these plots, red and orange areas consists of acceptable seal strength. It can be recorded that the optimum operating parameters using Tool 1 ranges between 120 to 130 °C sealing temperature with 1 to 1.5 s dwell time, except for Plastic 50.

Figure 25 presents fiber-based and thermoplastic polymer contour and 3D plot using Tool 2 sealing profile. Considering these plots, red-orange areas were significantly noted at sealing temperature 130 °C with 0.5 to 1 s dwell time. Tool 2 provided a narrower processing window for fiber-based and Plastic 15-35. At higher temperatures, the sealing layer was significantly torched and teared, therefore it is better to be avoided to achieve acceptable seal.

From figure 26, the fiber-based and thermoplastic polymer contour and 3D plot using Tool 3 sealing profile. Similarly, fiber-based and Plastic 15-35 demonstrated an acceptable heat seal range of 130 °C sealing temperature with 0.5 to 1s dwell time. Above this sealing range, the laminate layer becomes weaker leading to complete delamination.

The plots presented in figure 24 to 26 clearly presents the purple to dark blue region. This range of colors presents the lowest seal strength. At low sealing temperatures and dwell time, adhesive molecules do not fully crystalline and cause interdiffusion of chains. Therefore, it would make it hard to achieve high seal strength.

There are several key factors to achieve a good seal. When the two adhesive layers are in contact, it requires high temperature to melt the molecular chains in crystalline form and to diffuse across the interface. Gradually, upon cooling, these molecules form entanglements and recrystallize after sealing. Dwell time is another reasonable factor to increase the diffusion coefficient. (Mueller et al., 1998, p. 2029) This phenomenon was only achieved over range of temperature exceeding 110 °C for fiber-based material, 120 °C for Plastic 15-35 and 140 °C for Plastic 50 with 1 s dwell time. Therefore, the suggested optimum processing parameter is to use sealing temperature 130 °C with 1s dwell time for production.

It is clear the fiber-based material had attractive results than the thermoplastic polymer. The Fiber 120 recorded a higher seal strength than Fiber 85. This is because the Fiber 120 has thicker lamination which poses stronger inter diffusion of adhesives molecules across the laminated layer. The cellulose polymer joints play primarily important role in strengthening the paper materials. The paper materials delivered desired outcome as compared to the OPP films. (Zhao & Kwon 2011, 557). According to Clark and Wagner (2002, p. 147), the OPP is a non-conductive material which induces static. He concluded that the film distorts causing unattractive sealing at high temperatures above 145 °C. This was not the case with the thermoplastic polymers used in this experiment. For example, the Plastic 15-35 showed sealing distortion above 120 °C.

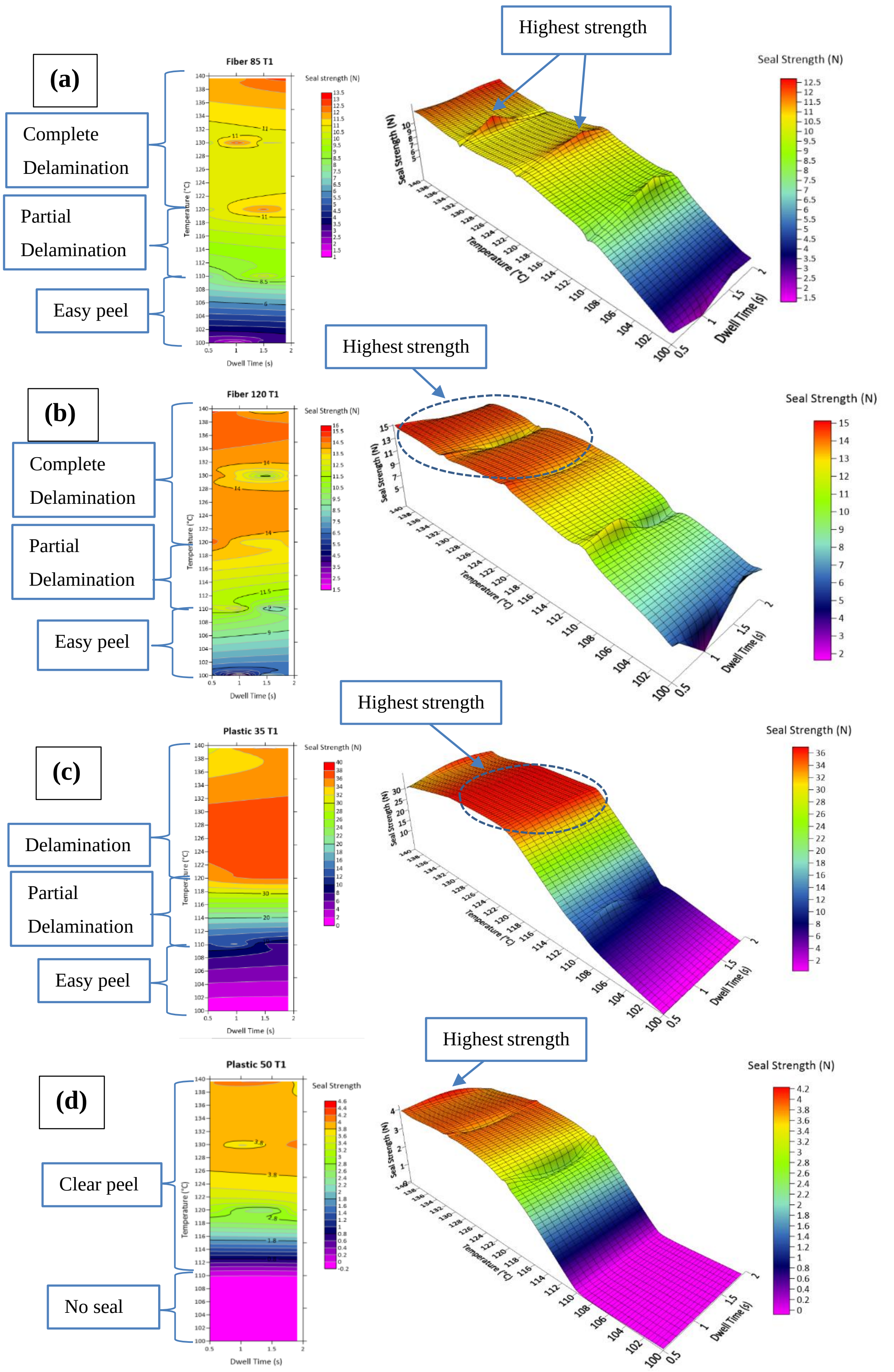


Figure 24. Sealing temperature versus dwell time for optimum seal strength and processing window using Tool 1 for (a) Fiber 85 (b) Fiber 120 (c) Plastic 15-35 and (d) Plastic 50.

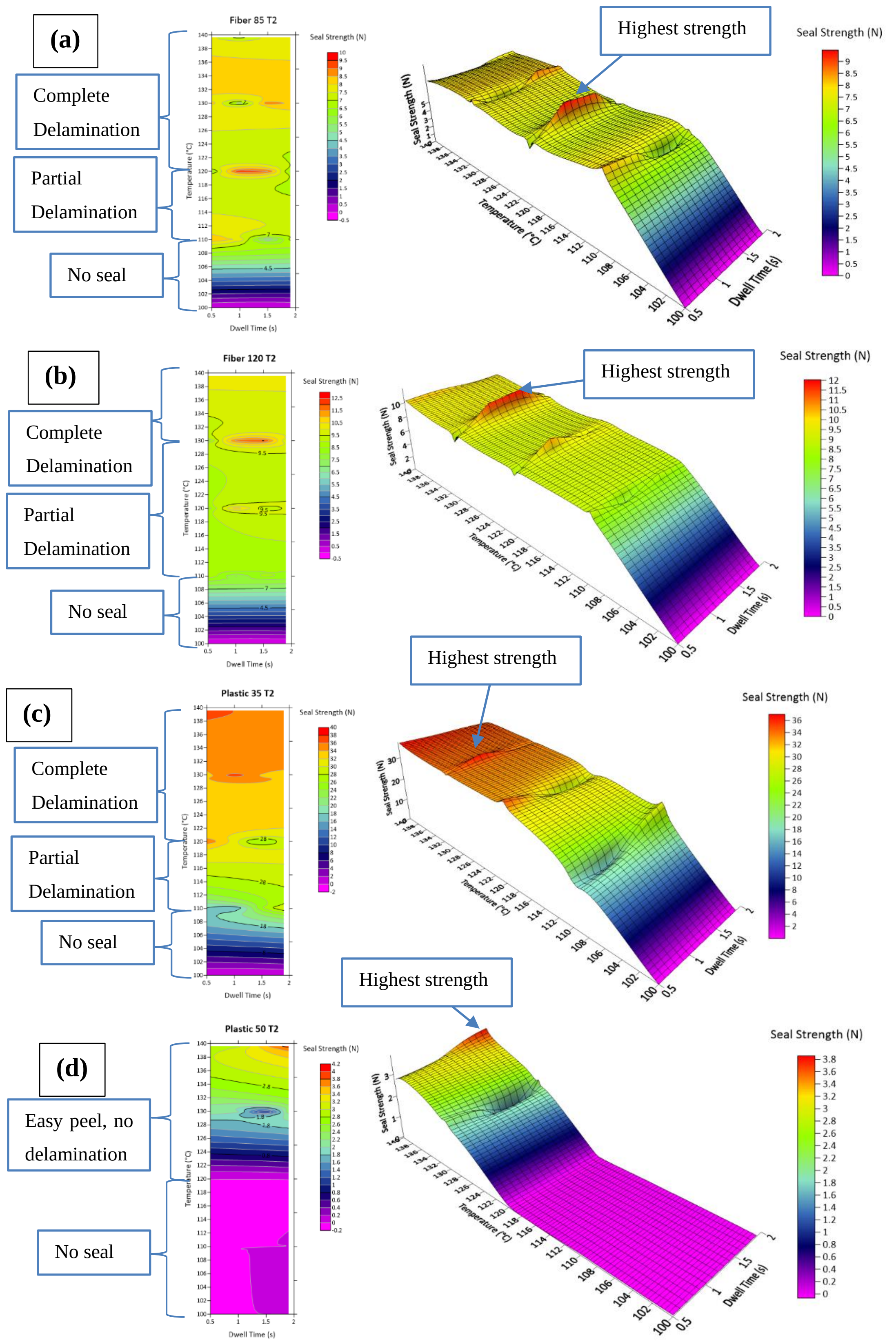


Figure 25. Sealing temperature versus dwell time for optimum seal strength and processing window using Tool 2 for (a) Fiber 85 (b) Fiber 120 (c) Plastic 15-35 and (d) Plastic 50.

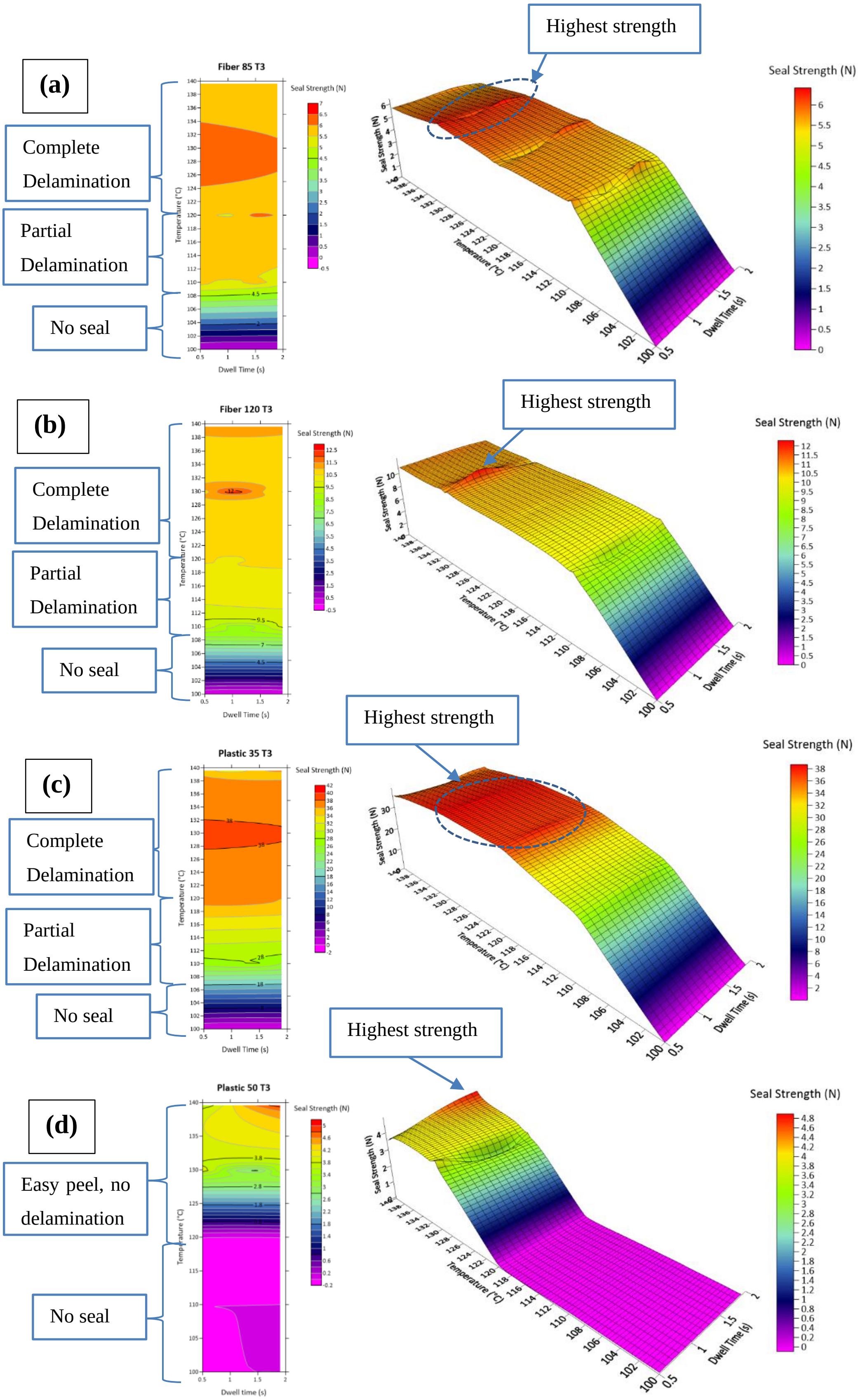


Figure 26. Sealing temperature versus dwell time for optimum seal strength and processing window using Tool 3 for (a) Fiber 85 (b) Fiber 120 (c) Plastic 15-35 and (d) Plastic 50.

4.5 Produced bags

GKS VFFS machine was used to produce pillow and block bottom bags by filling 400 g of peas through dispensing dozer. Both bag types consist of 3 seams, longitudinal seam and top and bottom seam. The top and bottom seams were made with Tool 1, serrated tool profile. As film is passed through the forming tube, the bags form a fold-over longitudinal seam. This allows one edge of the film to be folded inside of the other edge. The sample pillow and block bottom bags are presented in section 4.5.1 and 4.5.2, respectively.

The major requirement for the VFFS machine is to fill the products in the bags rapidly and to secure air-tight bags. Increasing the production rate is a key factor for profitability and pay back. With this regard, the bags were produced with an optimum sealing parameter of 130 °C sealing temperature with 1s dwell time obtained from contour and 3D plots. The VFFS parameters for pneumatic setting for film tension, belt transport, sealing jaws pressure and gusset pressure were conducted according to table 7.

As the heated jaws are compressed, the filling material (400 g peas) is dropped in dispensing dozer without any delay to simulate the real-life production line. This would allow us to verify the hot tack behavior of the fiber-based and thermoplastic material. This is a critical property in VFFS machines because the weight of product dropped exerts high force on the bottom seam. To avoid hot tack behavior, adhesive layer should solidify quickly to limit any possibility of seal distortion and leakage of the filling material. The materials used in this experiment, Fiber 85 and 120 and Plastic 15-35 and 50, had sufficient hot tack strength which results in good seal. All these materials did not result in hot tack behavior.

4.5.1 Sample pillow bags

Pillow bags have been successfully produced with both materials using the VFFS machine. One major defect seen in pillow bags is the formation of crinkles. Generally, crinkles form on the heat sealed edge of the pillow bag during heat sealing due to the bag’s weight (Hishinuma 2009, p.76). With the fiber-based materials, this effect was seen on the sides of the pillow bag, shown in figure 27.

The Plastic 15-35 experienced crinkles on the top and bottom seam which could have been caused due to excess weight and/or volume of the bag's content. Whereas, the Plastic 50 had no crinkles. The crinkles in the pillow bags have been identified with dashed circles in figure 27. The figure presents the front view and back view which consists of longitudinal seam side.

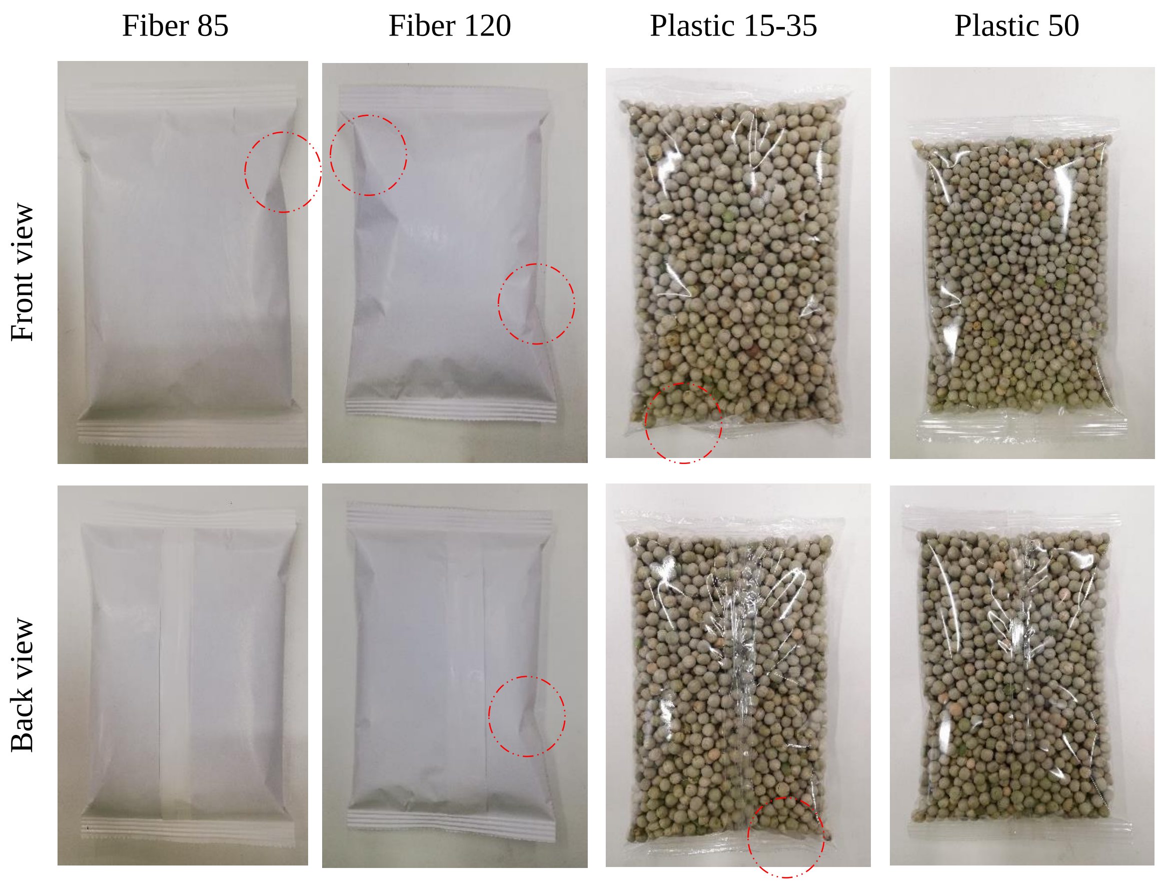


Figure 27. Pillow bags filled 400 grams of peas Fiber 85, Fiber 120, Plastic 15-35, Plastic 50. The crinkles effect presented in dashed circles.

4.5.2 Sample block bottom bags

Another form of bag produced uses variation of gusset shaped tools shown in figure 28 for the formation of block bottom bag. These bags provide a great alternative to have a retail display and stand-up bag. Production of block bottom bags using fiber-based materials was among the hardest. The top and bottom gusset caused cracks and holes to the bags due to high force of the gusset. The fractures caused on the block bottom bags was inconsistent. Several fractures were seen on the behind the longitudinal seam, holes at the closure bottom gusset and above the bottom cross seam sealing jaws. It is possible that these gusset spreads are too sharp when directed to fiber-based material. Lowering the gusset pressure from pneumatic valves reduced the performance of gusset spreads. Figure 28 presents a summary for various defects seen in the bags after filling 400 grams of peas and closure of the gusset.

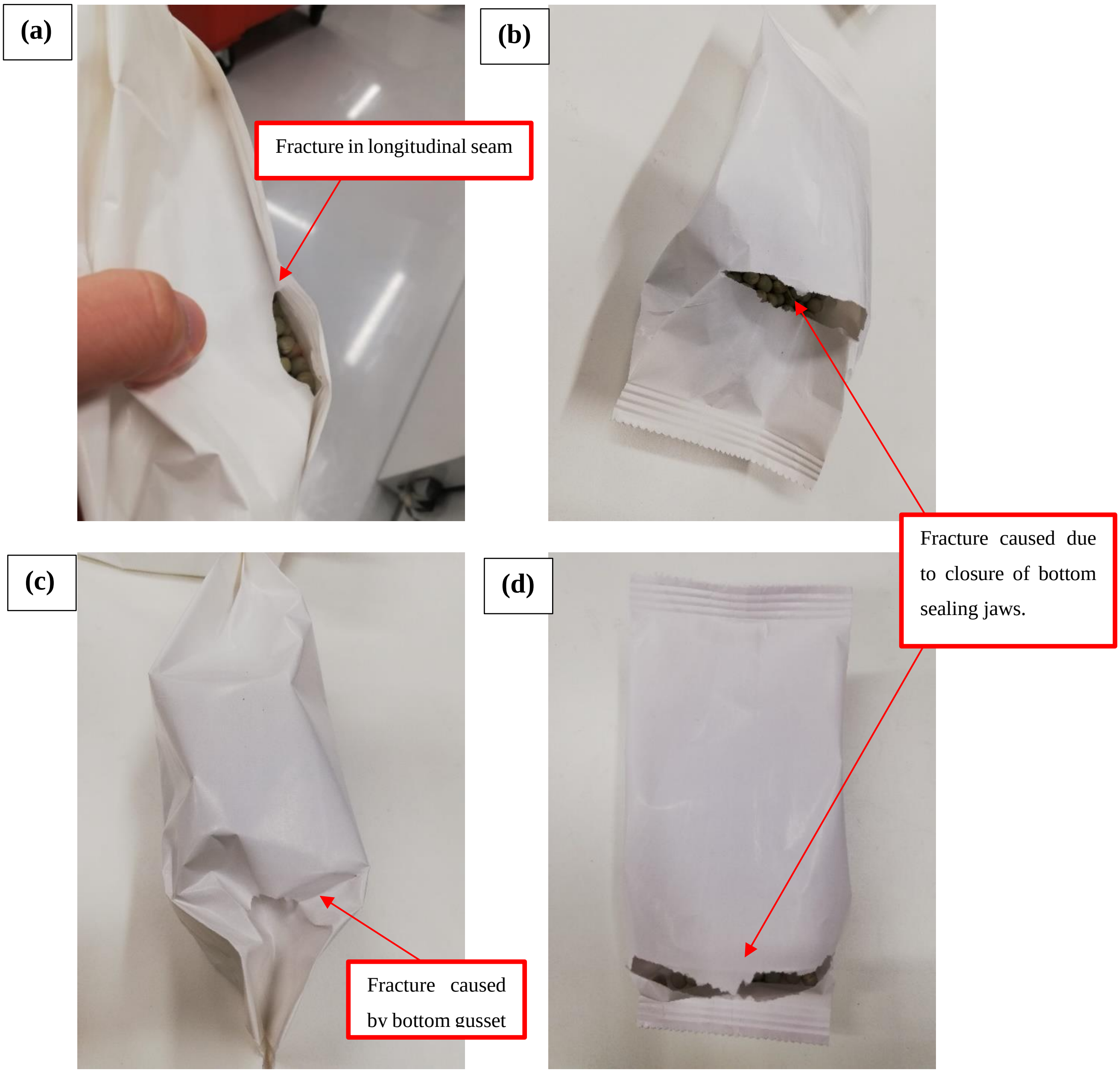


Figure 28. Fractures and defects on sample block bottom bag filled with 400 grams of peas (a-b) Fiber 85 and (c-d) Fiber 120.

The folds of the block bottom bags are made by the gusset spreads. After careful inspection, it was recognized that the top and bottom gussets are miss aligned which is the root cause of crinkles shaped bags and possible fracture. It was also observed that the tightening nob for the gusset is only from one end which shifts gussets towards the left. Figure 29 presents the misalignment of the gusset spreads after tightening the nob.

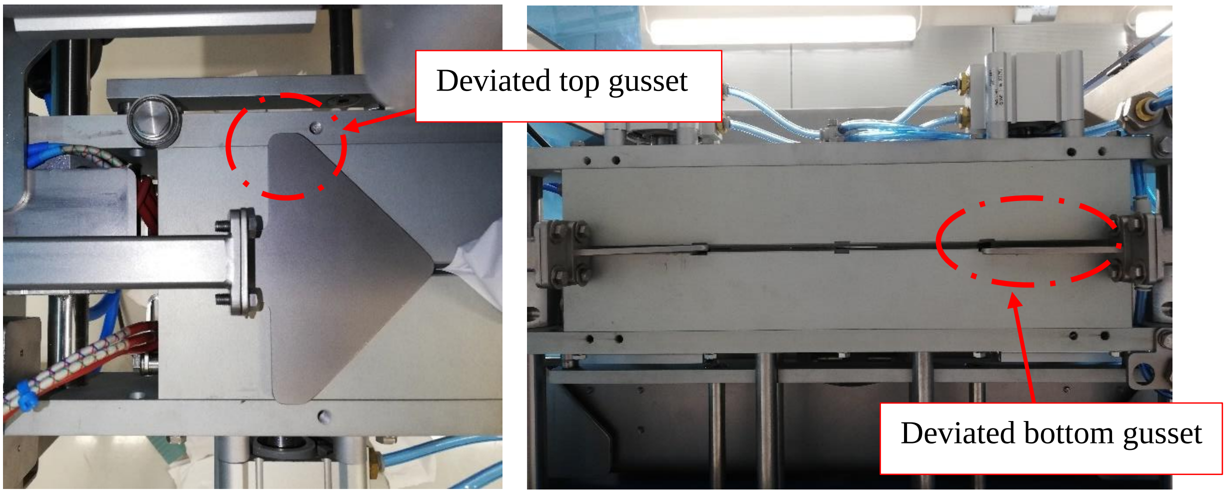


Figure 29. Miss alignment and deviation of top and bottom gusset after tightening the nob.

Successfully produced the block bottom bags filled with 400 g of peas are presented in figure 30. The figure presents fiber-based and thermoplastic material shown from different angles. Minor adjustments were implemented. The gusset was carefully monitored to avoid any damage and reduce the stress on the block bottom bag. The top and bottom gusset were slightly pulled, approximately 2 mm to the back, to reduce the depth of inserted gusset to the fiber-based material. Also, once the peas were placed in the dispensing dozer, the bags were held from the bottom to support the weight of the bag and minimize the fractures caused.

Wrinkling phenomena was seen with naked eye in pillow and block bottom bags on fiber-based materials. According to Hishinuma (2009, p. 83), the wrinkles are caused due to excess pressure of heat jaws on the material. However, from this experiment, it was recognized that the fillet on the edge of the forming shoulders could have been the major source of this issue. To further investigate the cause of wrinkling, two different types of shoulders has been tested, optimized small shoulder and medium sized shoulder. This is selection is demonstrated in detail in surface roughness test in section 4.6.

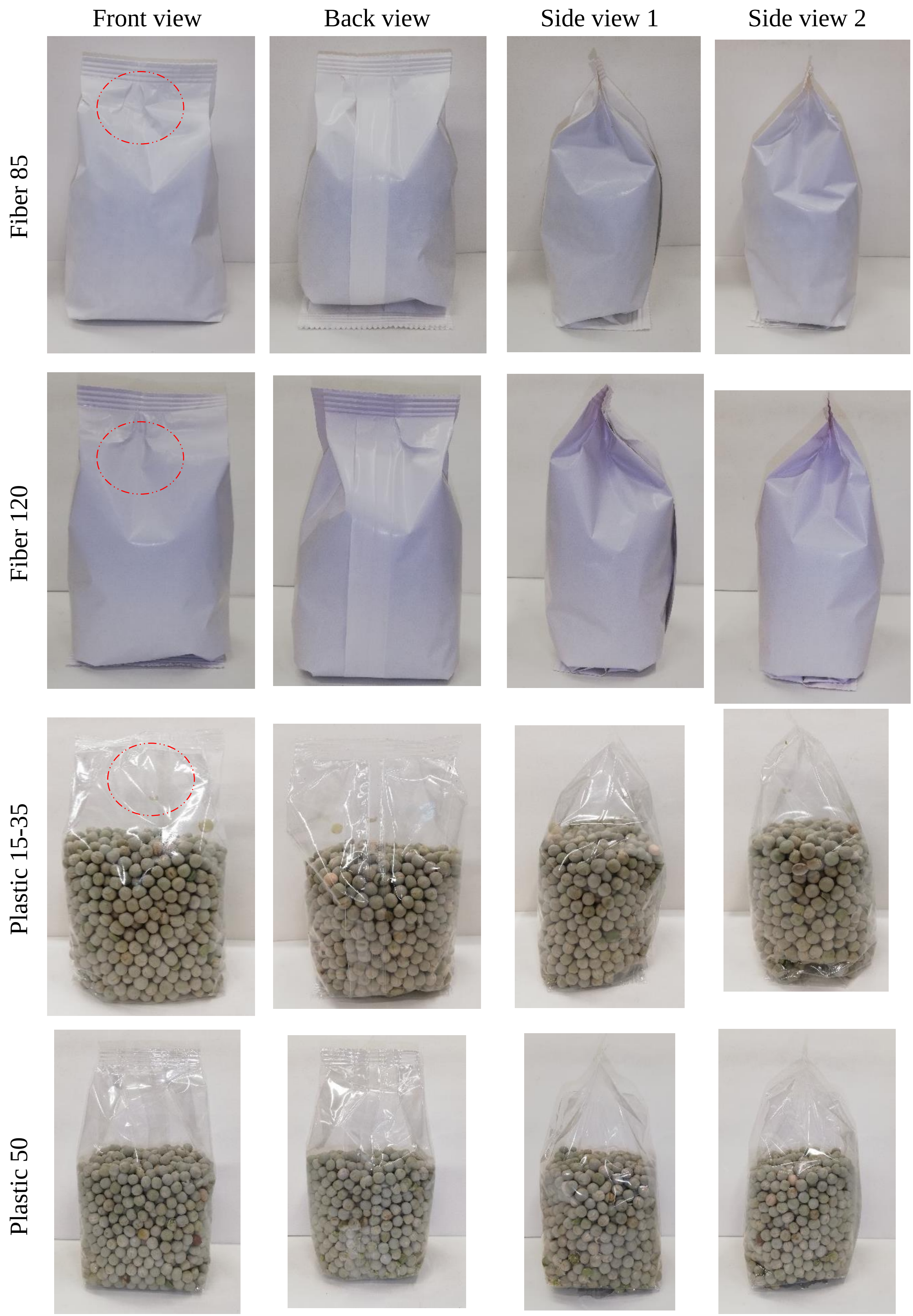


Figure 30. Block bottom bags filled 400 grams of peas Fiber 85, Fiber 120, Plastic 15-35, Plastic 50. The crinkles effect presented in dashed circles.

Table 8 summarize the length of the pillow and block bottom bags. From the VFFS, the setting bag lengths was 230 mm. All bags have been filled with equal amounts of peas, however, the results in the table conclude that the lengths are not consistent nor equal. It is possible that the thickness of the bags causes these minor differences. Further investigation is recommended to understand how the thickness of the film affects the total lengths and the shrinkages caused in the bags.

Table 8. Lengths of produced pillow and block bottom bags.

	Fiber 85	Fiber 120	Plastic 15-35	Plastic 50
Pillow bag (mm)	220.1	210.7	210.2	210.7
Block bottom bag (mm)	160.0	150.2	150.5	150.2

4.6 Surface roughness test

As discussed in table 3, only optimized small and medium sized shoulder were capable for producing pillow bags. In this section, the surface quality will be analyzed to investigate the effect of wrinkles with different shoulder types using the 3D profilometer. These wrinkles are formed due to the sharp fillet on the edge of forming shoulder. High wrinkling effect causes results in quality loss of the product (Hashimoto 2007, P. 935). Figure 31 below presents wrinkles observed from Fiber 85 after being passed through medium sized shoulder.

Figure 31. Wrinkles formed on Fiber 85 from medium sized forming shoulder.

The images were captured with 12x magnification in cross-direction with a scanned surface roughness area of 50 mm x 100 mm. The sealing conditions for the pillow bags produced in this experiment are based on the VFFS parameters in table 7. The roughness values are measured in micrometer.

Both samples, before and after being passed by the forming shoulders are measured and compared. A 3D image of the surface roughness for Fiber 85 is presented figure 32 below. As can be seen, the average surface roughness before being passed over the forming shoulder is about 8 µm. As the film passes over the shoulder, the average surface roughness triples to about 31 µm.

Before After

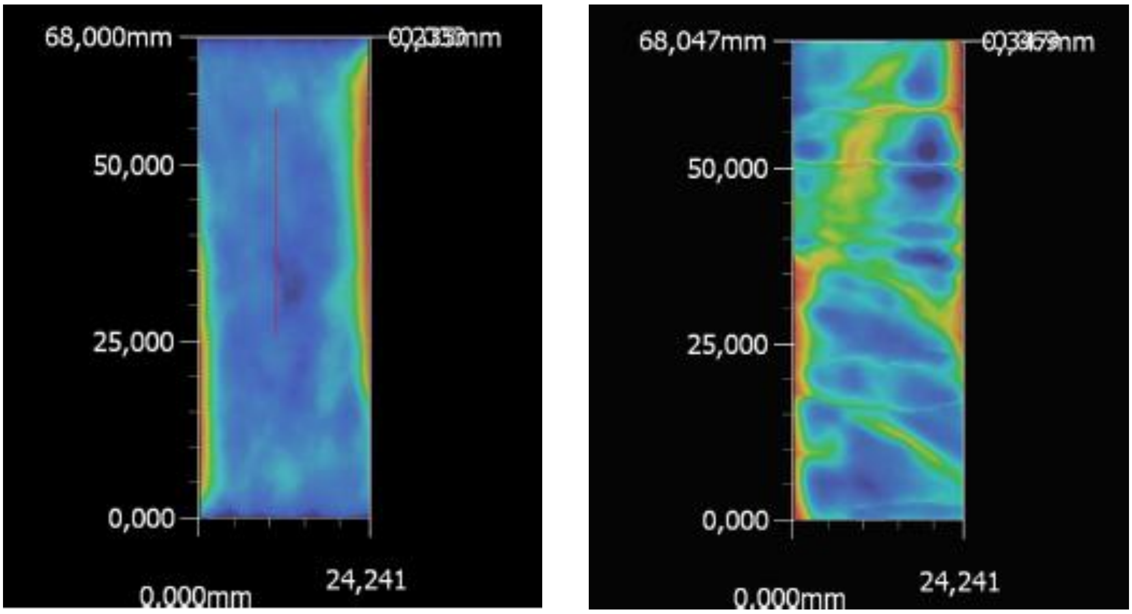


Figure 32. 3D image of the surface roughness of Fiber 85 before and after being passed over the medium sized forming shoulder.

The surface roughness of the pillow bags are analyzed and presented in the form of bar graphs in figure 33 (average roughness, Ra) and figure 34 (average peak roughness Rz). From figure 33 and 34, a strong correlation can be noted from both roughness parameters. The initial roughness values (before being passed over the forming shoulder) for fiber-based materials were relatively low and smooth. However, the roughness value tripled on average with Fiber 85 and quadrupled with Fiber 120.

The medium sized shoulder resulted in lower roughness as compared to the small optimized shoulder, especially with Fiber 85. Firstly, this is because the Fiber 85 has lower overall stiffness and more flexibility to bend as compared to Fiber 120. Secondly, the medium sized shoulder had smoother filet edge with minimum bending angle. The larger bending angle creates smoothness as the paper tends to flow over the forming shoulder.

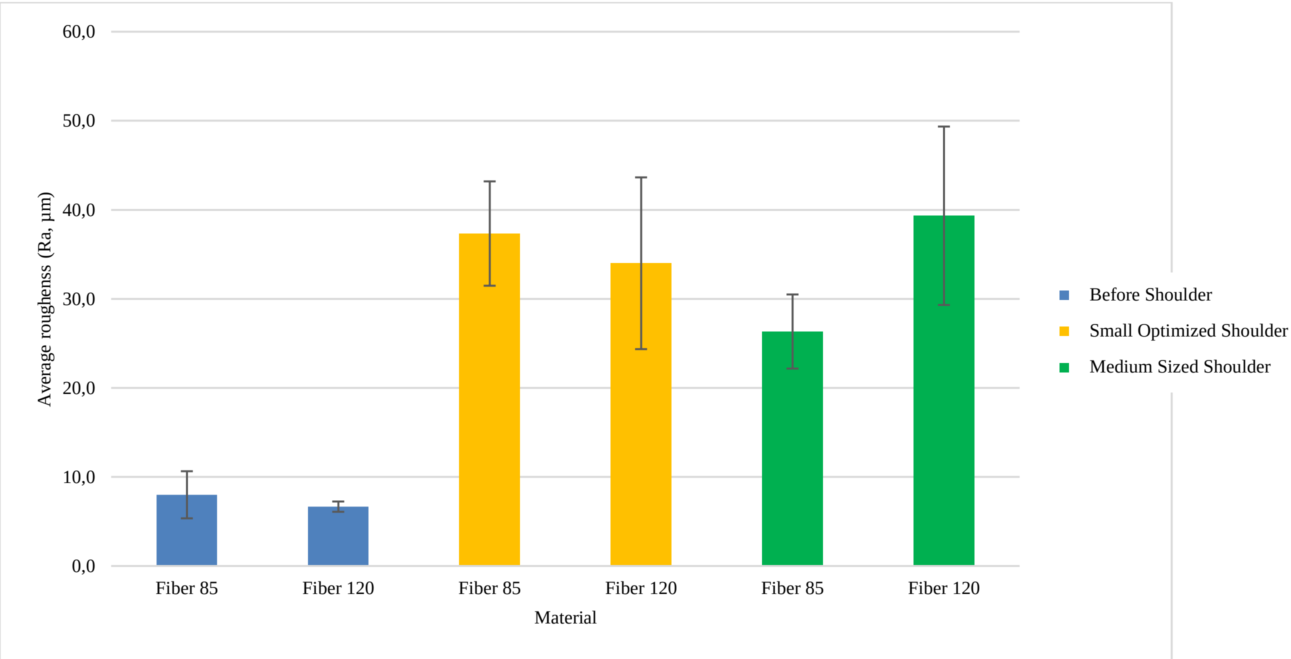


Figure 33. Average roughness (Ra, µm) for Fiber 85 and Fiber 120 with different small optimized shoulder and medium sized shoulder.

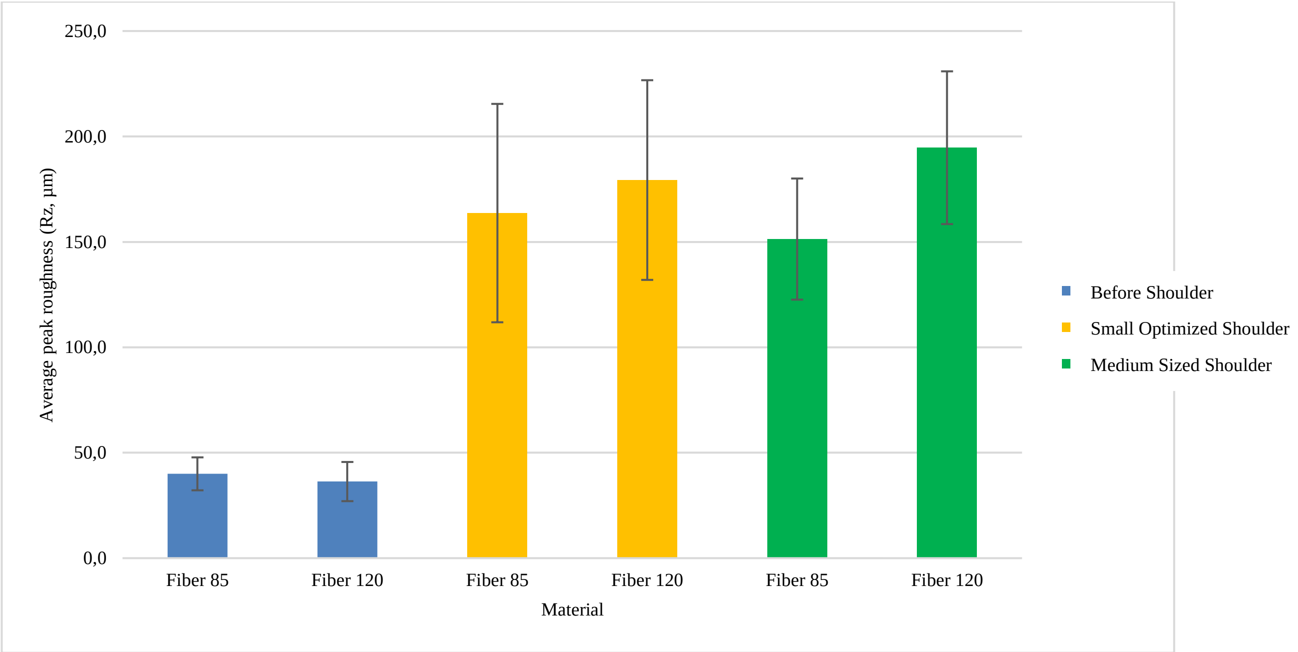


Figure 34. Average peak roughness (Rz, µm) for Fiber 85 and Fiber 120 with different small optimized shoulder and medium sized shoulder.

5 IMPROVEMENTS

There are opportunities for improvement to enhance the runnability of the fiber-based material with the current VFFS machine at the Laboratory of Packaging Technology in LUT. Several modifications and necessary customizations are discussed below.

5.1 Moisture content control

Flexible packaging material is very sensitive to the surrounding environment. In order to improve the runnability of the fiber-based material, it is recommended to be keep the material in the humidity chamber room from the date of unpacking. This is to guarantee that the material would maintain same moisture content as prescribed from the manufacturer.

5.2 VFFS recommended improvements

There are several improvements required for the current VFFS machine. These include

- temperature control of the heat jaw system,
- pneumatic system control unit,
- forming shoulder and tube,
- film handling unit.

5.2.1 Temperature control

There should be controlled temperature distribution across the heat jaw system. The current VFFS has a heat source only from end which lead to different temperatures across the heat jaws as discussed in section 4.2.1. To improve this variation, the temperature distribution should be constant across the heating jaws, the heat source should be located adjacent to the tools to reduce fluctuations between set and actual temperature. It is preferable to have one heat source in the middle or two heat sources in the ends to have accurate heat transfer across the sealing jaws.

During the experiment, it was noted that Tool 5 had a temperature variance of 15 %, and hence this has caused trouble for heat sealing of the fiber-based and thermoplastic materials. The PTFE coating should be roughened with sandpapers because the coating acts as insulating material.

5.2.2 Pneumatic system

It was concluded that each material requires appropriate pressure adjustments due to different material properties of the films. The pneumatic unit consists of various pressure control settings for different parts of VFFS system. To improve the runnability of the material, belt transport and film tension requires constant pressure calibration depending on the material.

As it is inconvenient to open the pneumatic box every time, it is recommended to place the valves near the control panel or implement a digitized control unit. The suggested location is presented below in figure 35.

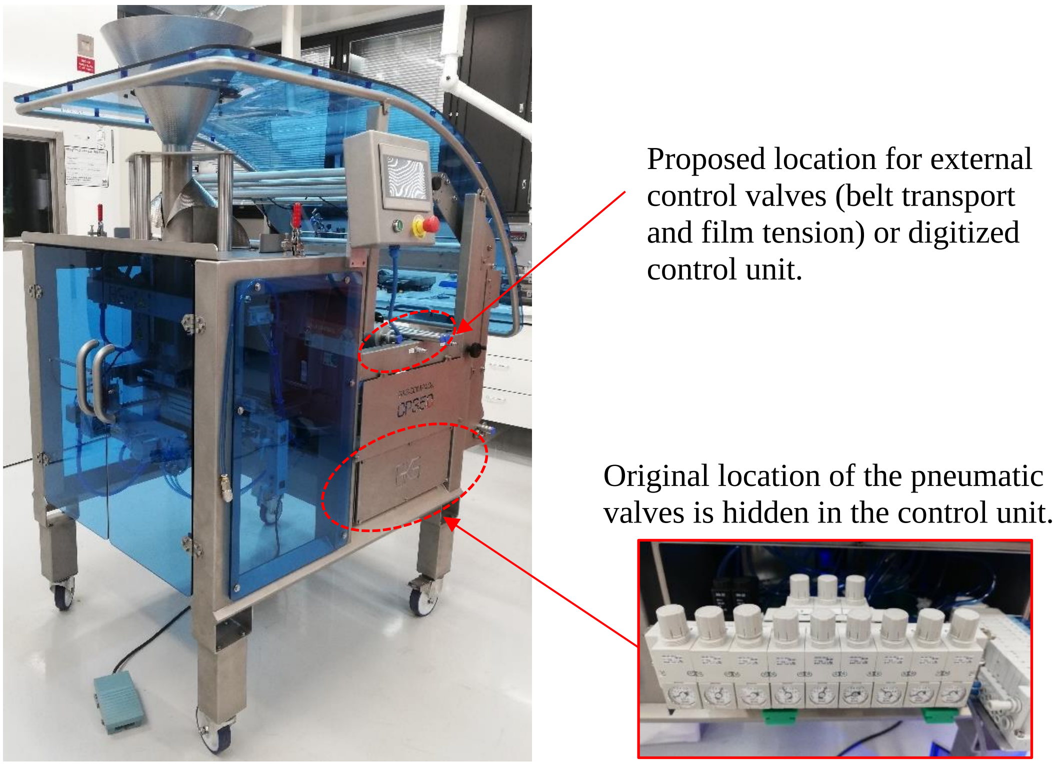


Figure 35. Suggested locations for external or digitized control unit.

5.2.3 Forming shoulder and tube

The forming shoulder is the critical feature in VFFS machine. It consists of a wing shape which is responsible to run the film over the shoulder into the forming tube. From this experiment, only optimized small shoulder and medium sized shoulder was used to produce pillow bag samples. It was observed that wrinkles were generated due to sharp fillet at the edge of the forming shoulder as the film is passed into the forming tube.

The booklet Guide to Vertical Form-Fill-Seal Baggers (2014) stated the steeper the run-in angle of the forming shoulder, the better possibility to track the film web. However, sharper run-in angle requires narrower fillet towards the forming tube and more pulling force from the machine. Eventually, this would lead to wear, wrinkles or tear of the packaging material.

In many sectors of the packaging design industries, parts development involves many trial and error, however this is time consuming and costly. (McPherson et al. 2005, p. 199) To have successful operation, there are two critical elements in the forming shoulder, namely shoulder geometry and material surface roughness. The theory behind forming a smooth with minimum distortion shoulder geometric design requires an understanding of complex mathematical modeling such as finite element method (FEM). (Desoki, Morimura and Hagiwara 2010, pp. 36-46)

Shoulders are traditionally manufactured by bending the flexible metal sheet along a molding forming shoulders (Boersma and Molenaar 1995, p. 406), where one of the sheets forms the collar and the other a tube (McPherson et al. 2005, p. 200). However, this manufacturing method develops a sharp fillet edge. Thus, it creates distortion along the bending curve which consequently makes the film not suitable to run smoothly over the shoulder. (Desoki, Morimura and Hagiwara 2010, pp. 33-34) This is the exact phenomena which was observed in forming shoulders used from the GKS Compack CP 350 PLUS. The figure 36 presents the traditional manufacturing method.

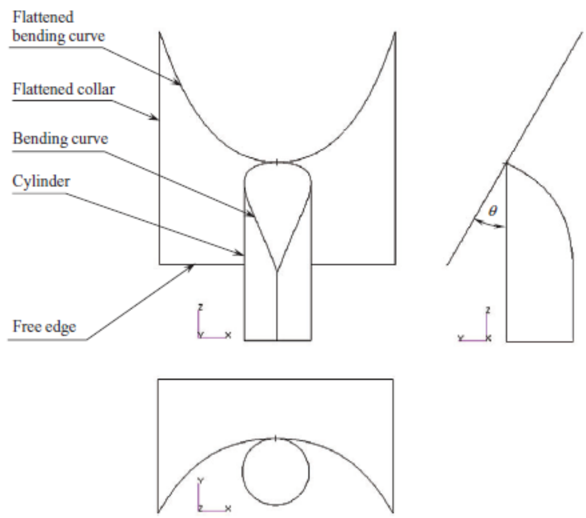


Figure 36. Traditional method for manufacturing forming shoulders. (Desoki, Morimura and Hagiwara 2010, p. 36)

Successful forming shoulder should guide the material from the film roll to the forming tube without wrinkling, tear or stretching. Suggested improvement to keep the smoothen the bending angle and sharp fillet is to use 3D printing. Computer-aided Design (CAD) and computer-aided engineering (CAE) can be utilized to design the forming shoulder. This method creates flexibility to optimized and calculate minimum distortion using FEM feature by simulating different material properties and performances. There are several designers, on a forum, who attempted to design and manufacture the forming shoulder using 3D printing. However, there are no relevant scientific literatures on this topic.

According to the Guide to Vertical Form-Fill-Seal Baggers (2014, pp. 23-24), forming shoulders are usually made from solid sheet metals either from bronze, aluminum, stainless steel or plastic. Metal based forming shoulders have lost their popularity in the market as they are heavy, difficult to handle and manufacture. Plastic forming shoulders are recommended as they provide smoother roughness layer, light, wear-resistant and less expensive. US based tools and machine service design company, GAZ Consulting, LLC, proposed a variety of forming shoulder designs made from fiberglass material as shown in figure 37 (Zjaba, 2020).

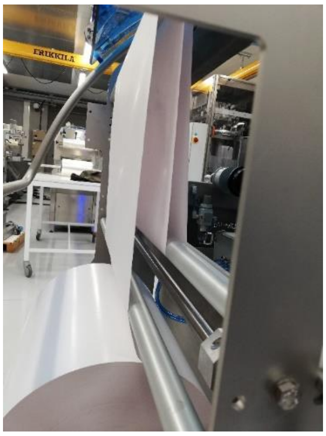
Figure 37. Forming shoulder samples made from fiberglass material (Zjaba, 2020).

5.3 Film handling unit

The transport belt system, located on the sides of forming tube, is responsible to pull the material from the film roll to the end of sealing jaws through. The film is usually passed through series of rollers. The GKS Compack CP 350 PLUS had a total of only 10 guiding rolls to the forming shoulder. As can be seen from figure 38 (left), the film lacks tension when the transport belt is not operated. Tight film web ensures that the film will not wander right and left as it passes through rollers.

It is possible to regulate the film tension by adjusting the pressure valves from the pneumatic unit. However, it was realized very high film tension leads to uncontrollable stretching of the film which creates difficulty in pulling the film. The Guide to Vertical Form-Fill-Seal Baggers (2014, p. 16) described a possibility to transport the film evenly by implementing dancer arm. The film is guided by the movement of a dancer that moves back and forth as shown in figure 38 (right). The spring mounted dancer arm uses the torsion spring mechanism to control the tension of the web film.

Another possible and low-cost solution to solve the tensioning issue to add additional transverse rollers in the GKS Compack CP 350 PLUS to reduce the unwinding of the film. Newly developed VFFS machine from GKS Leaf Series consists of many rollers (GKS Packaging, 2019). Also, to have a successful longitudinal overlap seam in the forming tube, the film should fit equally on the forming shoulder. GKS Leaf Series had implemented a transverse motion control of the spindle roll to match with the width of the shoulder using PLC system. Such control scheme could be implemented on GKS Compack CP 350 PLUS.



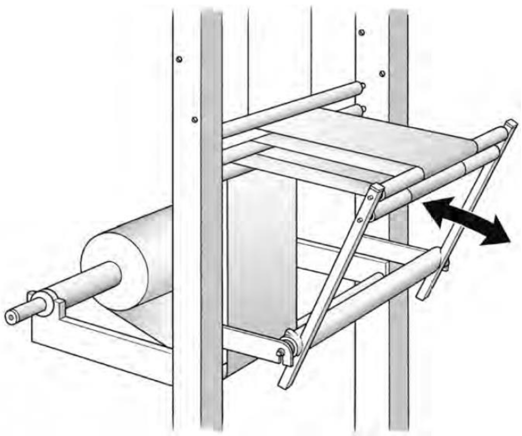


Figure 38. Loose film rolls seen from GKS Compack CP 350 PLUS machine (left image). Possible implementation of spring-mounted dancer arm (right)

6 CONCLUSION

Extensive research on optimizing the process parameters for VFFS machine was carried out with fiber-based materials for the first time. VFFS is widely used to form pillow and block bottom bags for packaging dried products. In production line, VFFS machine operates at a high speed, therefore it is very important to optimize the heat sealing parameters (sealing temperature, dwell time and sealing pressure) to achieve airtight and adequate seal strength. Each of these parameters, can be regulated individually. For example, high sealing temperature causes thermal expansion of the molecular chains in the adhesive layer. Addition dwell time and sealing pressure creates an interdiffusion of molecular chains by creating molecular entanglement in the adhesive layer.

The sealing strength was conducted as per ASTM F88 recommendation. The Shimadzu AGS-1kNX tensile machine was utilized. The prepared samples were peeled using T-peel method with 90° angle at a constant rate of 300 mm/min. Based on seal strength results, the study unfolded the processing window for the GKS Compack CP 350 PLUS VFFS machine using different sealing tool profiles.

Each sealing tool profile exhibited a unique load-displacement curves and failure modes depending on the material. Tool 1, serrated tool profile with 11 mm width, exerts high surface pressure on the film. At low temperature, about 100 °C, the samples exited easy peel regardless of the material. Majority of the graphs observed fluctuations after the first peak due to serrated tool profile. The sealing layer clearly separated from the adhesive layer. Tool 2 consists of two sealing surface area with 3 + 4 mm width. The load-displacement curves demonstrated two fluctuating peaks, whereas the first peak always had a lower seal strength. Majority of the samples were torn and delaminated from sealing layer. The highest surface pressure was recorded on Tool 3, with 5 mm width. This sealing tool did not exhibit any easy peel phenomena as compared to Tool 1. The load-displacement graph demonstrated minor fluctuations after the first peak due to the air bubbles that are trapped in laminated layer.

As a conclusion, Too1 1 with serrated jaws is recommend tool profile both fiber-based and thermoplastic material. These sealing tools proved to have extra strength, sealing quality and perfect airtightness. However, regardless of the sealing tool profile, majority of the samples exhibited complete delamination above 120 °C sealing temperature. This is because when the two adhesive layers are in contact, the molecular chains in crystalline form completely melts and diffuse across the interface. Upon cooling, molecules form entanglements and recrystallize.

The processing window for the VFFS machine was validated using contour plots and 3D mapping. It can be concluded that the Fiber 120 has a higher seal strength than Fiber 85. One possible reason is because Fiber 120 has thicker lamination which required higher strength to peel the adhesive layer. From the plots, it is concluded that the optimum operating parameters ranges between 120 to 130 °C sealing temperature with 1 to 1.5 s dwell time. However, Plastic 50 is an exception due to higher sealing temperature requirement to melt the adhesive layer.

Samples bags were produced using Tool 1, serrated tool profile, with sealing temperature of 130 °C and 1 s dwell time. All samples exhibited sufficient hot tack strength; therefore, the selected materials did not result in hot tack behavior. One major defect seen on pillow bag samples is the formation of crinkles which is caused due to the weight of the bag. The gusset used to produce block bottom bags caused cracks and holes during closure of the gussets. During production, after filling the peas through dispensing dozer, the bag was held from the bottom to support the weight and the gusset were pulled about 2 mm to the back to minimize the fractures on block bottom bags. Both sample bags revealed wrinkles on the bags surface which was caused due to the sharp bending angle and fillet edge of the shoulder.

The wrinkles were further measured with 3D profilometer, Keyence VR 3200 using 12x magnification. The surface roughness was measured in cross direction of the wrinkles. For example, Fiber 85 and 120 surface roughness tripled and quadrupled, respectively as it was passed over the forming shoulder. The Fiber 85 is more flexible and consist of lower stiffness which makes it easy to form over the shoulder.

Several development opportunities were found during the research work. Firstly, flexible packaging paper is recommended to be kept in humidity chamber from the date of arrival. This is to make sure the material does not lose it moisture content. Secondly, redesign the forming shoulder using CAD and CAE to minimize distortion of bending angle. The new shoulder would be 3D printed to keep smooth fillet edge. At last, improve the film handling unit by implementing spring-mounted dancer arm and PLC system which tracks and centers the movement of the film between the shoulder and roll. With these improvements, the runnability of the fiber-based materials can be enhanced substantially.

7 FUTURE TESTS

As discussed, the aim of this experiment was to determine the appropriate sealing parameters, runnability of fiber-based material and roughness surfaces of packages. There are many aspects in this field of research which have not been explored yet. The suggested continuation and future tests are presented:

- Evaluation of hot tack strength. ASTM F1921 describes the standard test method for hot tack seal strength (ASTM F1921, 2018). Further investigation to determine the molecular diffusion limits and appropriate seal strength with variety of processing parameter. To achieve this, a narrow processing window should be considered to develop a trend between hot tack strength and sealing temperature.
- Further investigation of peel test under different environmental exposures. As we live in a cold climate, it is likely that the stored bags in the factory would remain in cold shelves for a while before being distributed to the consumers. Conducting peel test under different environmental exposure would allow to further understand the strength of the adhesive and laminated layer.
- The ASTM D5276 – 19 specifies a vertical impact testing method for specified packs (ASTM D5276, 2019). This test would allow us to examine the impact strength to determine the ability of the pack to withstand free fall.
- Friction test will be conducted on the fiber-based material using the friction device available at Laboratory of Packaging Technology. Evaluation of COF would further clarify the runnability of the material using numerical analysis.
- Bursting strength of pillow and block bottom bags using Shimadzu AGS-1kNX. This would enable us to measure the strength of the bag and how it could withstand excessive pressure of the sealed product.
- Profilometer test will be re-examined with larger sample size to investigate the surface roughness of the complete surface area of pillow and block bottom bags. Additionally, determining the effect of surface roughness of the seams with different sealing tools could be a plus.

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APPENDIX I, Peeling test samples of Fiber 85, Fiber 120 and Plastic 50

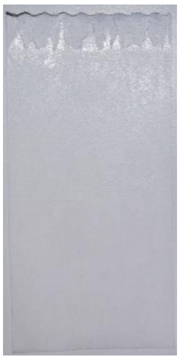
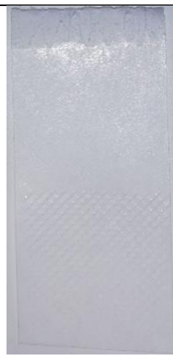
Fiber 85 using tool 1 after peel test samples

Time (sec)		0.5	1.0	1.5	2.0
Temperatures (°C)	100				
	110				
	120				
	130				
	140				

Fiber 85 using tool 2 after peel test samples

Time (sec)		0.5	1.0	1.5	2.0
Temperatures (°C)	100	No sealing			
	110				
	120				
	130				
	140				

Fiber 85 using tool 3 after peel test samples

Time (sec)		0.5	1.0	1.5	2.0
Temperatures (°C)	100	No sealing			
	110				
	120				
	130				
	140				

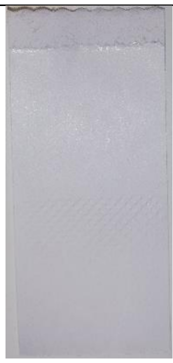
Fiber 120 using tool 1 after peel test samples

Time (sec)		0.5	1.0	1.5	2.0
Temperatures (°C)	100				
	110				
	120				
	130				
	140				

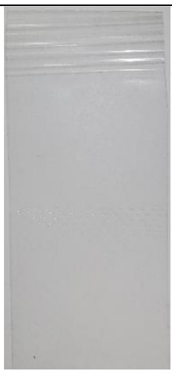
Fiber 120 using tool 2 after peel test samples

Time (sec)		0.5	1.0	1.5	2.0
Temperatures (°C)	100	No sealing			
	110				
	120				
	130				
	140				

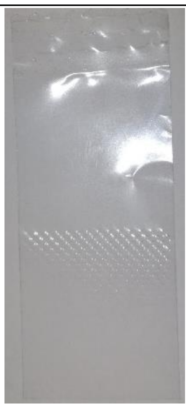
Fiber 120 using tool 3 after peel test samples

Time (sec)		0.5	1.0	1.5	2.0
Temperatures (°C)	100	No sealing			
	110				
	120				
	130				
	140				

Plastic 50 tool 1 after peel test samples

Time (sec)		0.5	1.0	1.5	2.0
Temperatures (°C)	100	No sealing			
	110	No sealing			
	120				
	130				
	140				

Plastic 50 tool 2 after peel test samples

Time (sec)		0.5	1.0	1.5	2.0
Temperatures (°C)	100	No sealing			
	110	No sealing			
	120	No sealing			
	130				
	140				

Plastic 50 tool 3 after peel test samples

Time (sec)		0.5	1.0	1.5	2.0
Temperatures (°C)	100	No sealing			
	110	No sealing			
	120	No sealing			
	130				
	140