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ZIPPY RELEASE

Does zippy release affect dispensing of self-adhesive labels

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TIIVISTELMÄ

Unna Paavolainen: Tarralaminaatin epätasaisen laadun havainnointi etiketöinnissä
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Avainsanat: tarralaminaatti, etiketti, irrotuskoe, etiketöinti, epätasainen laatu.

Etiketit ovat isossa roolissa jokapäiväisessä elämässä. Etiketeillä voidaan välittää tietoa, ohjeistaa kuluttajia ja koristaa erilaisia pakkauksia. Etikettien yleisimpiä loppukäyttökohteita ovat muun muassa suuri osa elintarvikepakkauksista, hygieniatuotteista sekä nestepakkauksista. Informatiivinen etiketti kertoo kuluttajalle tuotteen olennaiset tiedot, joiden perusteella kuluttaja pystyy tekemään ostopäätöksen. Myös visuaalisesti miellyttävät etiketit herättävät kuluttajan huomion. Lisäksi etiketin teknisiä ominaisuuksia voidaan muokata loppukäyttökohteen mukaan.

Työssä tutkitaan niin kutsuttua ”zippy”-ilmiötä, joka aiheuttaa hyvin epätasaisen kuvaajan laminaatin irrotuskokeessa, eli kokeen aikana ilmenee suuria voimavaihteluita. Työn tavoitteena on selvittää aiheuttaako kyseinen ilmiö ongelmia tarralaminaatin jalostuksessa ja etiketöinnissä. Työn teoriaosassa esitellään etikettien monikerroksinen rakenne, joka koostuu pintamateriaalista, liimasta, silikonikerroksesta ja taustapaperista. Jokaisella komponentilla on tärkeä rooli tuotteen toimivuuden ja valmistuksen kannalta. Pintamateriaalin tärkein vaatimus on taata hyvälaatuinen painatus, kun taas liiman täytyy tarttua hyvin moneen erilaiseen pintaan. Silikonikerros ja taustapaperi huolehtivat liiman puhtaudesta ja tasaisesta irtoamisesta taustasta. Tarralaminaattirullat valmistetaan pitkissä suurinopeuksisissa koneissa, joissa tarralaminaattien kerrokset kasataan yksi kerrallaan taustamateriaalista pintamateriaaliin. Materiaali valmistetaan isoissa tarralaminaattirullissa, jotka sen jälkeen voidaan jalostaa halutunlaisiksi etiketeiksi. Laminaatin tuotannossa olennaisin asia ominaisuuksien kannalta on antaa liimalle ja silikonikerrokselle tarvittava aika reagoida ja kypsyä korkeissa lämpötiloissa.

Tutkimuksessa tarkasteltiin kymmentä eri testimateriaalia, joista osassa ilmeni selkeästi epätasaista laatua. Irrotuskokeet tehtiin jokaiselle koemateriaaleille kuudella eri nopeudella, jotta voitiin havainnoida nopeuden vaikutusta ilmiön suuruuteen. Tuloksien perusteella suuremmilla nopeuksilla tehdyissä irrotuskokeissa zippy-ilmiö oli huomattavasti pienempää kuin matalien nopeuksien kokeissa. Etiketöinnissä havaittiin merkittäviä eroja materiaalien käyttäytymisien välillä mutta tulokset eivät korreloineet irrotuskokeissa esiintyneen zippy-ilmiön kanssa.

ABSTRACT

Unna Paavolainen: The occurrence of zipping phenomenon in dispensing of labels and its effects on it
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Key words: self-adhesive labels, laminate, release test, dispensing, zippiness

Labels are actively taking part in our daily lives, Labels are able to provide consumers with information, provide guidance and decorate otherwise dull looking packages. The most common end-uses for labels are for example grocery packages, hygiene products and liquid packages. Informative labels give the consumer relevant knowledge of the product, with which the consumer is able to come to a purchase decision. In addition, visually pleasing labels attract the attention of consumers. The technical properties of labels are typically customized based on their end-use restrictions and conditions.

This study investigates the phenomenon of zippiness, which creates an uneven graph during release measurements, by causing continuous peaks to the graph. The peaks originate from changes in the required force in the release measurements. The aim of this study is to investigate whether this phenomenon causes issues during label dispensing.

In the theory part of this study, the complex structure of labels is introduced, which consists of a face material, an adhesive, a release coating and a backing material. Each of these components has an important role, so that the label functions and is produced correctly. The most important feature of the face material is its printability, whereas the adhesive has to provide proper adhesion to any substrate. The release coating and backing material provide a protecting layer for the adhesive and smooth release from the backing material. The laminate reels are produced in long high-speed coating machines, in which the layers of the laminate are accumulated one by one from backing material to the face material. In general labels are produced in big laminate reels, which can be then converted into labels. The most important factor during production is to give enough time for the adhesive and release coating to react and cure in high temperatures.

The study investigates ten different materials, of which some showed uneven quality during release. Release tests were done with different speeds and the results showed that the zipping decreased significantly as speed increased. Dispensing tests showed variations in the behavior of the test materials, but the results did not correlate with zippiness found in release tests.

PREFACE

This work was carried out in collaboration with UPM Raflatac, Tampere. The experimental measurements were performed at UPM Raflatac with the help of their experts. I would like to thank UPM Raflatac for this opportunity to conduct this experimental work with them.

Firstly, I would like to thank Sipi Asu from UPM Raflatac, for organizing this opportunity for me. Special thanks go to my supervisor from UPM Raflatac to Tero Metsäjoki for all the help in organizing the trials, measurements and providing me with support throughout the project. I would also like to thank David Hate from UPM Raflatac for additional guidance during this project. A thank you to Heidi Haapaniemi from UPM Raflatac as well for the converting and dispensing laboratory measurements during this difficult time. At TUT, I would like to thank Sanna Auvinen for guidance and support during this project.

Tampere, 20.04.2020

Unna Paavolainen

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1. INTRODUCTION

Labels are dominantly present in our everyday lives even though they are not often paid attention to. Labels are our guide to many things; they are primarily produced for the purposes of identification, information, instruction or decoration. Labels are the end-product of a long production chain, the final product before converting the label is self-adhesive laminate. Self-adhesive laminate can be produced in large reels varying in different lengths and widths.

The structure of labels can be slit into four distinct components; face material, adhesive, release agent and the backing material. Each of these components serve a crucial role in producing labels successfully. Face material is important as it is the component that for example product information is printed on and adhesive is the component that ensures that the label attaches properly to a substrate and stays adhered for long periods of time. Release agent provides a surface from which it is easy for the label to be removed, and lastly the backing material provides an application layer for the release coating as well as cover to the adhesive from dirt and other particles that could weaken the adhesive properties. As the production is done into big reels of laminate, the material still needs to be converted into labels before dispensing them on to a substrate. During the conversion process the material is die-cut into required label shape using a sharp die-cutting tool. During matrix removal, the unnecessary material surrounding the cut labels is removed, and after this the material is rewound into a reel again. Finally, the labels can be dispensed to different substrates, for example bottles, and shipped out to shops, where they become available to consumers.

This study aims to investigate the effect of zippiness occurring during the release of labels. Zippiness can be defined as a phenomenon in which the face material is removed from the backing unevenly, causing continuous peaks in the release force graph. There are certain known silicone recipes which react with a hotmelt adhesive causing zippiness. The research question for this study is whether this zippy release phenomenon affect dispensing of self-adhesive labels.

The study aims to produce different levels of zippy release in materials. During this study ten different test materials are produced, with varying silicone recipes. The material is then first examined with different release tests, to determine the level of zippiness. Then the materials are dispensed to investigate whether zippiness can be seen in these stages of label production. Most of the test results are presented through data and graphs, but also visual results are of importance. The conclusion of the results aims to provide sufficient analysis of the results at different speeds and implicate possible root causes for the phenomenon.

2. SELF-ADHESIVE LABELS

Self-adhesive labels are complex sandwich structure products which are extensively used in many different end-uses. During production each of these components are layered on top of each other to form this sandwich structure with unique properties. Image 1 shows the basic structure of self-adhesive labels.

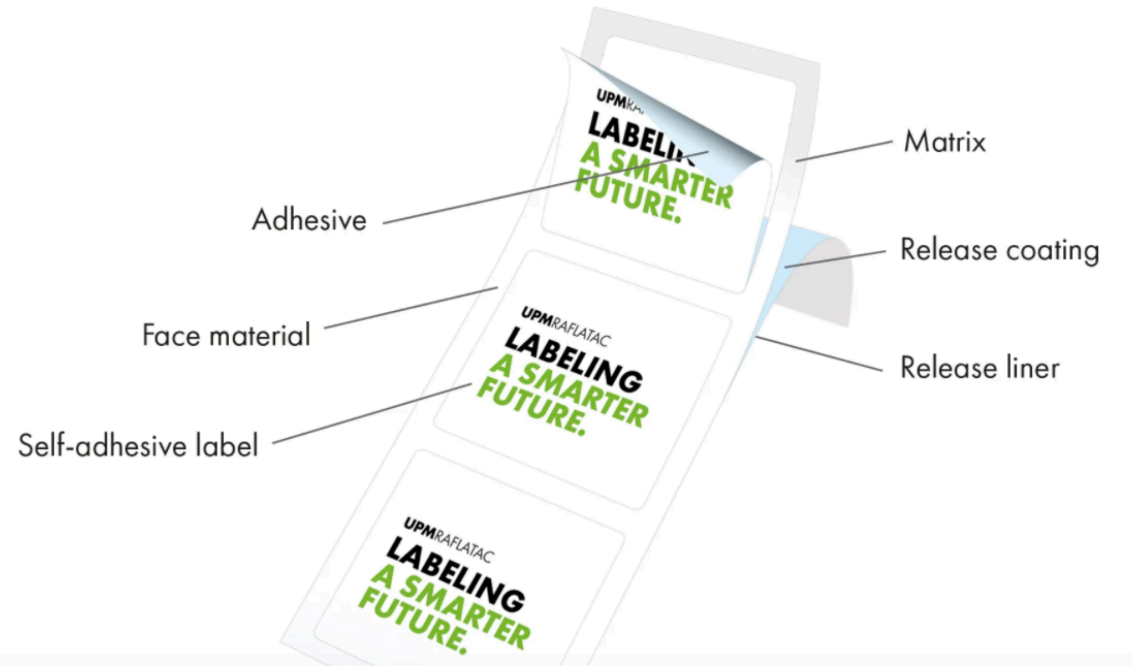


Image 1: Basic structure of self-adhesive labels [1]

The structure of self-adhesive labels consists of four main components: face material, adhesive, release coating and backing material. Each component serves an important role in the main function of self-adhesive labels, and all of them are critical in order for the label to perform.

2.1 Face

The most important property of the face material is its printability. Also, the choice of face stock material can make a great difference in the visual appearance of the labels. There is a wide range of different face stock materials. Paper face stock alone has multiple different materials such as uncoated, machine coated or high-gloss-coated paper. Plastic film materials can also be used as the face material for labels. Most common plastic film materials include polyester

(PET), polypropylene (PP) and polyethylene (PE) films. The choice of face material is heavily influenced by its end-use application. For example, labels on wine bottles tend to be much more attractive than the labels used for medicine packaging. [2, p. 130]

2.2 Adhesive

The different adhesives that are used in the production of self-adhesive labels are more commonly called pressure-sensitive adhesives (PSA). The name originates from their capability of adhering to different kinds of surfaces upon small pressure or contact. The most important requirement for PSA is their ability to instantly adhere to a substrate. At the same time it is necessary for the adhesive to wet the surface of the substrate and allow a certain amount of flow in order to fill the uneven surface of the substrate. [3, p. 8] Adhesives can be categorized into three main groups based on their adhering properties: removable, semi-permanent and permanent adhesives. [4, p. 3]

Acrylic based adhesives are to this day the most common and versatile adhesives on the market. Acrylic based adhesives have a large range of glass transition temperatures (T_g), which has a high impact on the adhesive properties, as they are highly dependent on this temperature. Acrylic based adhesives have good thermal stability, and UV- light resistance. In addition, they are typically transparent and exposure to sunlight does not affect their color. However, there is another type of adhesive that differs widely in terms of composition which is called hot-melt pressure-sensitive adhesive. [3, pp. 6-10]

Hot-melt pressure-sensitive adhesives are thermoplastic and are commonly a combination of four components: a thermoplastic elastomer, tackifier resin, a plasticizer oil and other additives like antioxidants. [4, p. 3] Hot-melt pressure-sensitive adhesives are complex structure compounds, as they gain their good properties from the morphology and structure of block copolymers which are the most commonly used polymer types in PSA. Block copolymers generally follow a chain-like structure with hard end-block structures in both ends of the chain. The mid-block chain section of the structure has elastomeric like properties such as being soft and flexible with a quite low glass transition temperature (T_g). However, the end-block structures have contrary properties as they possess a much higher glass transition temperature greatly above room temperature and are much harder than the chain structure. The most typical block copolymer type that is being used in the self-adhesive labels is the styrene block copolymers (SBC) in which styrene acts as the end-block structure. Out of this category of block copolymers, styrene-butadiene-styrene (SBS) and styrene-isoprene-styrene (SIS) are the most commonly used structures. [5, pp. 166-160]

2.3 Release coating

The release coating is one of the most important components of self-adhesive labels. When combined with a suitable backing, they protect the label from impurities and disturbing particles such as dust. The release coating is a necessary component in the construction of self-adhesive labels due to it preventing the adhesive from adhering to the backing material, allowing the intended face material and adhesive to be removed from the backing. [6]

2.3.1 Requirements

Other than serving the purpose of a layer in between the adhesive and backing material, the release coating has other essential functions that can be adjusted by the different substances in the release coating recipe. The release coating must produce a satisfactory release level of self-adhesive labels. This means that the release level is required to be low enough for the labels to unwind effortlessly during dispensing. Additionally, the release level cannot be too low, as this will cause the labels to fly off the backing material before dispensing as there are not enough forces to keep the label attached to the release coating. With different labels this level of release is unique and often require a lot of product testing before making it to the market. [7, pp. 585-587]

Another requirement for the release coating is its reproducibility. As labels are mostly produced in massive rolls, it is important that throughout the product, there is no significant variation in the release level of the label, as this would cause inconsistency issues. This concern can be reduced by minimizing the amount of release agent used and assuring that the release of the labels is not quite sensitive to the amount of release agent. In addition, the possibility of aging should be taken into consideration while developing the release coating for a label. It may be that the labels are not instantly adhered to their product thus the release coating cannot be time sensitive. This means that the release coating must perform at its required level for longer time periods as well. [7, pp. 585-587]

Lastly, the release coating is required to properly adhere to the backing material. In other words, the release coating must be cured well, and be resistant to transferring to another surface like the adhesive layer. The improper anchoring can result in weakened properties of the attachment of the label. In addition, the transfer of release coating to the backing can cause conversion and printability issues, as in a roll the backing is exposed to the sensitive face material. These are all important factors of the release coating which must be considered in production in order to be able to deliver satisfactory labels to the consumer. [8, p. 1]

2.3.2 Properties of silicone

Currently, silicone is the most common polymer used in release coating as it has many good properties that keep the coating as stable as possible throughout production. Similarly to carbon, silicone has four valence electrons, thus being able to construct multiple bonds. [5, p. 437]

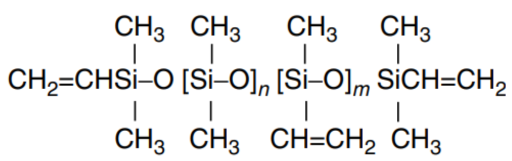


Image 2: Silicone polymer structure used for release coating [5, p. 431]

On the contrary, silicone is less electronegative, and due to this it can establish much more stable single bonds with oxygen than carbon, which is known to promote double bonds with oxygen more than single bonds. Due to this, silicones are quite flexible, as the silicone-oxygen single bonds give it complete rotational freedom, which many organic polymers cannot accomplish. [6]

Silicones have a flexible chemical structure as it can be established in the chemistry of organosilicon. In this chemistry both the silicon-carbon and silicon-oxygen bond influence the properties of silicone. Good electrical insulating, low intermolecular forces causing low surface tension and low density are just a few of the many properties of silicone. [8, p. 2] However, the beneficial properties of silicone in label production include its chemical inertness as well as satisfactory thermal stability in both high and low temperatures with which it can withstand the various production temperatures without any shifts in its molecular structure. Most importantly silicone possesses low surface energy which gives it stable release properties, that are necessary throughout the conversion process. Additionally, silicone is a competent polymer for the release coating as it allows the laminate to be either rolled or sheeted, as it provides necessary adhesion between the silicone coating and adhesive to keep the laminate together throughout handling and dispensing. [7, pp. 585-626]

Lastly, as a result of having numerous methyl groups in its chemical structure, silicone has good hydrophobicity. This means that a small amount of release agent including silicone can be used to cover quite a large volume of backing material, as good hydrophobicity causes spontaneous spreading of the substance. [6]

Overall, due to chemical and physical properties as well as financial point of view, silicone seems to be one of the most used primary polymers in release coating mixtures. Even though as a substance it can be quite costly, the amount used for a large volume remain small and therefore economically advantageous. This further contributes to the ability of customer-friendly pricing, even with specialty labels. [6]

2.3.3 Silicone release coating

The release coating is a complex structure itself in label production. The release coating of self-adhesive labels is made of four main components: a polymer, crosslinker, catalyst and modifier. Each of these components serve a purpose as they all alter the processing and performance of the produced labels. [7, p. 605]

The selection of the solventless polymers contribute as the base component for the release coating, and it has a great impact on the final release. The structure of the base polymer has an effect on the release values and profiles. There are multiple different solventless release polymer types which each have unique properties. The different types can be classified according to their polymer structures. The four main types are end-blocked polymers, multifunctional polymers, pendant polymers and branched polymers. [5, p. 432]

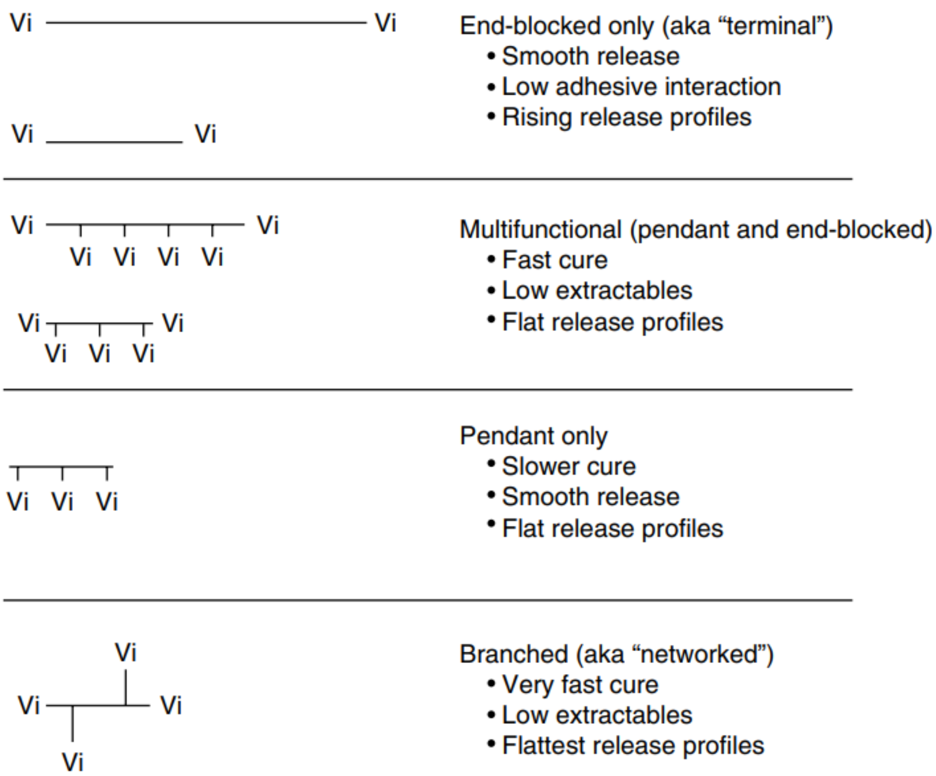


Image 3: Different structures of release coating polymers [5, p. 432]

Image 3 shows the different structures of release coating polymers and the properties which each of them possess. The end-blocked polymers are linear polymers, whereas multifunctional polymers are a combination of end-blocked and pendant structured polymers. Pendant polymers are branched chains, in which all branches are oriented in the same direction. Lastly, the branched polymers are very reactive due to their structure and therefore cure at extremely high rates. Each of these structures have different properties and thus the choice of polymer and its structure plays a great role in the performance of the release coating. [5, p. 433]

The most common silicone component is a polydimethylsiloxane polymer, also known as PDMS polymer. PDMS polymer possesses many great properties, such as high flexibility and significantly lower surface tension when comparing to organic adhesives. Due to the flexibility of the polymer and its low surface tension, PDMS molecules can shift freely in a broad temperature range. [9, pp. 356-359]

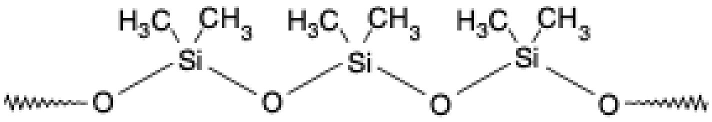


Image 2: The general structure of PDMS polymer [5, p. 426]

Typically, at room temperature PDMS chains appear amorphous and when cross-linked into a silicone coating, they acquire somewhat elastic properties. As elastic materials are capable of storing and returning energy to different sources, the stored energy generally causes low release forces. PDMS polymer can be quite easily altered, as numerous functional groups such as dimethyl groups can be substituted for methyl groups which gives the polymer better curing properties. However, the release performance is highly dependent on the dimethyl content of the coating. Therefore, it is of high importance to find a balance between a necessary curing speed and release performance. [5, p. 437]

Cross-linkers serve a purpose of linking polymer chains, thus creating a network of polymer chains. In release coatings, they can affect the anchorage, bath life and cure rate of the release agent. Good bath life of the mixture extends the timespan of the mixture, so that it is usable for a longer time period. Cross-linkers can be split into two distinct groups, homopolymers and copolymers. They vary in terms of properties due to their structure, such as molecular weight and the amount of dimethyl substitution. Homopolymers offer a fast gelation and good anchorage, however the cure rate is quite slow. On the other hand, copolymers have a good cure rate and they offer good bath life. It is common to create a blend of homo- and copolymers in order to reach a balance between these properties. While formulating the release coating, further flexibility is offered through the alteration of the so called hydrosilane groups (SiH) to vinyl ratio (SiH:Vi) on a molar basis. This is also known as the cross-linker to polymer ratio. For a justifiable cure rate, it is necessary to have excess SiH, so that the reaction progresses. High SiH:Vi ratios often enhance the anchorage, whereas lower ratios can be preferred as they can reduce the interaction with possible reactive adhesives. [5, pp. 430 - 440]

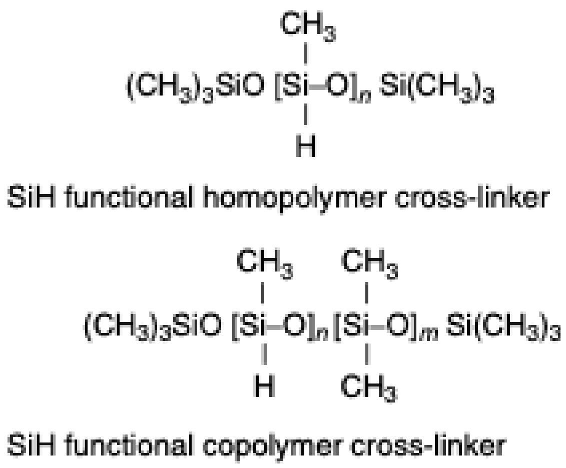


Image 4: General structures of two cross-linker types [5, p. 431]

Catalysts also have an impact on the cure rate and the bath life of the release coating. They typically consist of noble metal organo complexes, of which most common are platinum or rhodium organosilicone complexes. For solventless silicone coatings, platinum catalysts are usually used. In such catalysts, it is specifically the amount of platinum which directly affects the bath life and curing of the release coating. Catalysts can also play an active role on the coverage of the release coating as well as its anchorage. [5, p. 430]

Lastly, it is necessary for the release coating to contain a release modifier. Release modifier is typically a combination of a polymer, an inhibitor and a resin. The release modifier as its name suggests, can alter the release level of the material. In addition, it has an effect on the anchorage, bath life and cure rate of the coating. [5, p. 432]

2.4 Backing

The backing paper or otherwise known as release paper is the basis to which the release layer of the laminate is cured to. The backing material is usually made of paper, but plastic backing materials such as PET films have become more common as well. There are some requirements for the properties of the backing material that ensure good quality for the laminate. [10, p. 358]

Paper as a backing material is typically supercalendered glassine type kraft paper or pigmen coated kraft paper. Paper materials used for label production are typically made from chemical hardwood, softwood and pulp mixture. Glassine type paper often possesses high gloss and can be said to be almost transparent as it is so thin. In addition, it also has great strength properties and is therefore a suitable backing material for laminate production. In order for the release agent to apply to the surface of the release paper properly, it is necessary that the surface of the paper is dense and smooth. Dense is a requirement so that the release agent does not get absorbed by the paper, and the smoothness is needed so that the release agent applies evenly to the surface. In order for the release paper to withstand the continuous wetting and drying of the material, the paper also has to have good dimensional stability and necessary strength properties. [11]

2.5 Production

The laminating process begins with compiling the required raw materials to the coating machine. The production of laminate can be started once the raw materials have been put to the required positions. The lamination process always starts with the application of release coating onto the backing material. This can be done by two different methods: in-line coating and off-line coating. During In-line coating process the lamination is performed in one cyclic continuous operation. This means that by adding raw materials when necessary it is possible to produce laminate non-stop whereas in off-line coating only consists of the application and curing of release coating. When comparing the two methods, in-line application is usually more efficient even though production line speed is much faster with off-line application. In in-line application the limiting factor for the production line speed is often the adhesive drying rate. Some materials are also run off-line in order to confirm that the release coating has cured properly as uncured particles can cause transfer to the backing material and therefore to the face material, causing printability issues. [7, pp. 745-747]

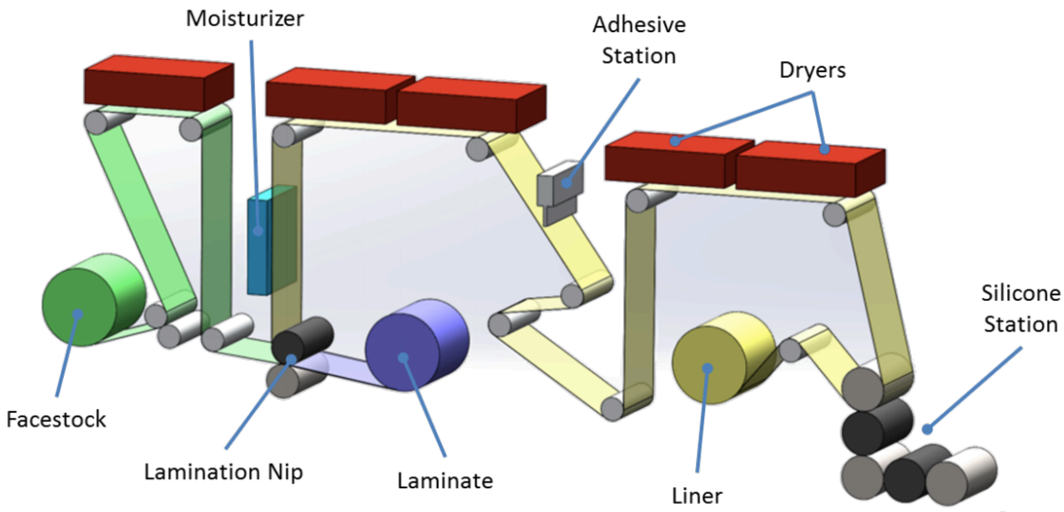


Image 5: The components of a coating machine [12, p. 13]

After the application and curing of the release agent follows the application and drying of the adhesive. The most common application method for adhesives is through transfer coating: the adhesive is spread on the release coating and dried. This method allows to avoid exposing the face material to heightened temperatures in which damage could occur to the printable material. In other words, transfer method of the adhesive is done to minimize the possibility of damage to the sensitive face materials.

Finally, the laminate is finalized with combining the face material to the multilayer structure. The finished product is often in a wide wound reel containing many thousand square meters of freshly made laminate. Due to the reel's large size and volume they often need to be handled into proper size for converting and printing. Handling is done with slitting machines which divide the reel into multiple smaller reels in width as well as length. [7, pp. 745-747]

2.6 Conversion and dispensing

After the laminate rolls have been produced, the process of converting them into labels begin. There are multiple steps in the process and there are plenty of elements that must be paid close attention to. Lastly, when the rolls of labels are finalized, they can be dispensed onto a surface.

Die-cutting is one of the key processes when it comes to successful label application. The die cutting the material should only pierce through the face material and the adhesive layer of the laminate. It is essential that the cutting of the silicone layer and the backing material is avoided as this causes breaking of the backing material and issues for the dispensing process. There are multiple designs for the cutting tool. The cutting die can be flat, rotary or wraparound. It typically depends on the demand for label production and the design of the conversion line. To reach a homogeneous die-cutting quality the die-cutting tool must be adjusted based on the thickness of the backing material. If this is not done successfully, the die-cutting will be too light or too deep for the laminate. Due to this the labels simply will not dispense properly, causing many of the labels to go to waste. It is important to sharpen or change the die-cutting tools in regular intervals to avoid dull cutters, which are unable to cut the material properly. [13, p. 7]

After the die-cutting has been done on the conversion line, the next step on the conversion line is the removal of the matrix, which in other words is the removal of the excessive face material surrounding the die-cut labels. When the matrix has been removed, all that remains are columns of labels on a wide master reel. As the dispensing machines typically can carry only smaller reels, the master reel can be slit and rewound into numerous smaller reels. In addition, the labels can be wound inside or outside of the reel, depending on the end-use application requirements of the labels. [13, pp. 7-8]

Some of the issues that improper re-winding process can result in is the incorrect winding tension which can cause the reel to telescope. This means that the reel can lose its desired shape, pushing the core of the reel away from its original position, making it impossible to use. Low tensions tend to cause accuracy issues during the dispensing process, while high tensions can cause adhesive bleeding, which can cause the failures in the label dispensing. [13, pp. 8-9]

The dispensing of the labels occurs when the labels are detached from the release liner by running the material over a sharp edge beak. The liner bends over the beak, but the labels are unable to follow the release liner and therefore comes off at the sharpest point of the beak. [13, pp. 8-9] Dispensing is used to apply labels to their end-use surfaces, such as bottles or other packaging.

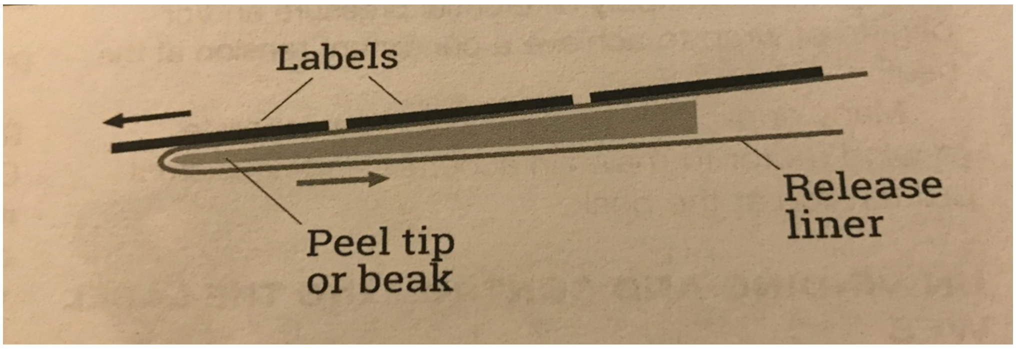


Image 6: Basic application of labels [13, p. 9]

Some labels may require a sharper beak than others in order to dispense properly. The sharpness of the beak required usually depends on the relative stiffness of the face material and the object that it is being dispensed to. [7, p. 758] There are three essential components that are necessary for each dispensing machine to have in order to be able to apply labels successfully. Firstly, the labelling head is necessary to feed the machine with labels, unwind the reel of labels and control the web path and web speed throughout the applicator. The release liner is responsible for pulling the material through the labelling beak, and it is important to be able to control the web tensions. This can be done by making sure that the pull of the release liner is greater than the push, to ensure successful dispensing. Another component in the dispensing machines is the applicator, also known as the dispensing beak. This component ensures peeling of the labels from their release material by pulling the backing material over a metal beak. [13, p. 8]

Image 7: An example of a typical dispensing machine [14]

The sharpness of the beak is defined by the radius of its tip. Several tests have shown that a 2mm radius beak or smaller is optimal for successful dispensing, as it causes the pull of release material at an angle of seven degrees. Lastly is the product handling system, which is responsible for speed of the applicator and placing the labels consistently on the right position on the substrate. This is generally done through a software, where changing the settings is much more efficient than doing it manually. [13, p. 8]

3. MEASURING MATERIALS, METHODS AND MACHINE

The materials for this study were chosen based on previous knowledge as to which material combinations are known to have zippiness in them. In order to receive processable data, tests are done on the chosen materials. Low speed release force and high speed release force tests are part of the standardized Finat testing methods [15, p. 5]. The dispensing machine used is located at UPM Raflatac at Tampere.

3.1 Materials

The choosing of different components for producing laminate were based on a few important facts. All the test materials had the same face material, adhesive and backing materials, so the effect of the stiffness and other possible factors of the materials could be minimized. This way it is possible to solely investigate the difference that the various silicone compositions establish. In addition, all the materials were produced the same way and using the same coating machine for all the materials.

The chosen face material is Raflacoat Plus PEFC, which is a white woodfree machine coated mid-gloss paper. It can be printed on with many different methods. Table 1 displays the basic properties of this face material.

Property	*Value*	*Unit*
Caliper	70	µm
Tensile Strength MD	5.8	kN/m
Tensile Strength CD	2.8	kN/m
Roughness	1.0	µm
Gloss	64	%
Stiffness MD	0.23	mNm
Stiffness CD	0.13	mNm

Table 1: Properties of Raflacoat Plus PEFC [16, p. 1]

The hotmelt adhesive that was chosen for this study is RH1, a strong permanent hotmelt adhesive. It is specifically developed for cold and humid environment. This naturally requires high initial adhesion forces. This adhesive possesses a great performance in particularly low temperatures, as its minimum labelling temperature is below zero degrees. It also has good adherence on non-polar surfaces, as well as to materials such as cardboard even in low temperatures. [17, p. 1]

Ten different release agent recipes were chosen to get various levels of zippiness with the different recipes. Within the recipes, there are five completely different recipes in terms of the polymer in the recipe. The other five recipes are the same as the five chosen recipes, except they contain some percentage of release modifier. The recipes are shown in table 2.

Release Agent Recipe	*Without release modifier*	*With modifier*
1	Test Material A	Test Material B
2	Test Material C	Test Material D
3	Test Material E	Test Material F
4	Test Material G	Test Material H
5	Test Material I	Test Material J

Table 2: Material pairs used for zippiness testing

This way the experiment has five different recipes with zero percent release modifier and some percentage modifier. With this, it is possible to see some differences due to the release modifier level.

Lastly, the backing material was chosen. The choice was a yellow transparent glassine backing paper called Honey Glassine 65. The basic properties of the material are shown below.

Property	*Value*	*Unit*
Grammage	57	g/m^2
Tensile Strength MD	6.2	kN/m
Tensile Strength CD	2.3	kN/m
Caliper	51	µm

Table 3: Properties of Honey Glassine 65 [18, p. 1]

This backing material is very suitable for specifically automatic dispensing. Additional requirements for this material during production is to rewind the reels so that the silicone layer is inside and to slit the reels to a minimum of 100mm in order to prevent possible telescoping of the material. [18, p. 1]

3.2 Production of test materials

The material required for testing has been produced as a trial laminate batch. Due to the use of hot melt adhesive in this trial experiment, the production of release coating is done with the off-line coating procedure. This also minimizes the risk of the release coating not curing all the way through. The off-line coating has been done on a coating machine which produces laminate with the width of one meter, and the machine that will be applying the hot melt adhesive and producing the complete laminate as its final product possesses the width of only 0.5 meters. Because of this, the material is slit in half. After slitting, the production can continue, and the product can finally be laminated. However, after the lamination of the product, it is still necessary to slit the material one more time to the proper width needed for the conversion machine and dispensing machine. After this final slitting, the material is ready for testing.

The samples need to be prepared properly before the testing can take place. For low speed release, the laminate must be cut into 50mm wide and minimum of 175mm length samples in the machine direction and for high speed release 25mm wide and 300mm long. This is usually done with a die-cutting tool as it gives straight cuts and minimum inaccuracy. The samples must be stored in standard test conditions of 23 ± 2 degrees Celsius and 50% ± 5% relative humidity for at least four hours before the testing can begin. Additionally, the samples are usually cut from A4 sample sheets, which are cut from the laminate straight after production. Due to this they are stored under a pressure of 6.86kPa for at least 20 hours to demonstrate the pressure inside the laminate reel, and to establish a satisfactory interaction between the adhesive and release coating. After these requirements are met, the testing can finally take place. [15, p. 12]

3.3 Low Speed Release Force – FTM3

Low speed release testing method examines the necessary amount of force used in order for the adhesive coated face material to separate from its backing material. This testing method can imply possible issues in the converting process and dispensing of the material. Low release values can suggest the possibility of labels not having the necessary adhesion to the backing whereas a high value release can cause issues during matrix removal. The procedure is often performed at an angle of 180 degrees, and a standardized jaw separation rate of 300mm per minute. The test is usually performed on a tensile tester, that has the ability to hold a back plate to which the test material can be attached. This way the testing can be done at 180 degrees. In addition, the tensile tester should have an accuracy of ± 2% in order to provide comparable results. [15, p. 12]

Image 8: Test method for FTM3 [15, p. 12]

The samples are adhered to the back strip using double-sided tape, ensuring that the sample can be separated at the required 180-degree angle. The upper jaw is attached to the material which is being peeled. Once the testing is completed, the results are given as the average force of the procedure and it typically possesses the unit of centinewton per 50mm width (cN/50mm). [15, p. 12]

3.4 High Speed Release Force – FTM4

High speed release testing method is used to evaluate the force required for the separation of the adhesive coated face material from the backing at high speeds. The high speeds varying from 10-300m per minute correlate to the different speeds used to convert and dispense the material. When comparing to low speed release testing, high speed testing gives more accurate estimation of the possible problematic properties for converting. This testing method can be used in two different ways; pulling the face material away from the backing or vice versa. There is a difference between these two testing methods, and it is common to purposefully use only one of these methods. [15, pp. 14-15]

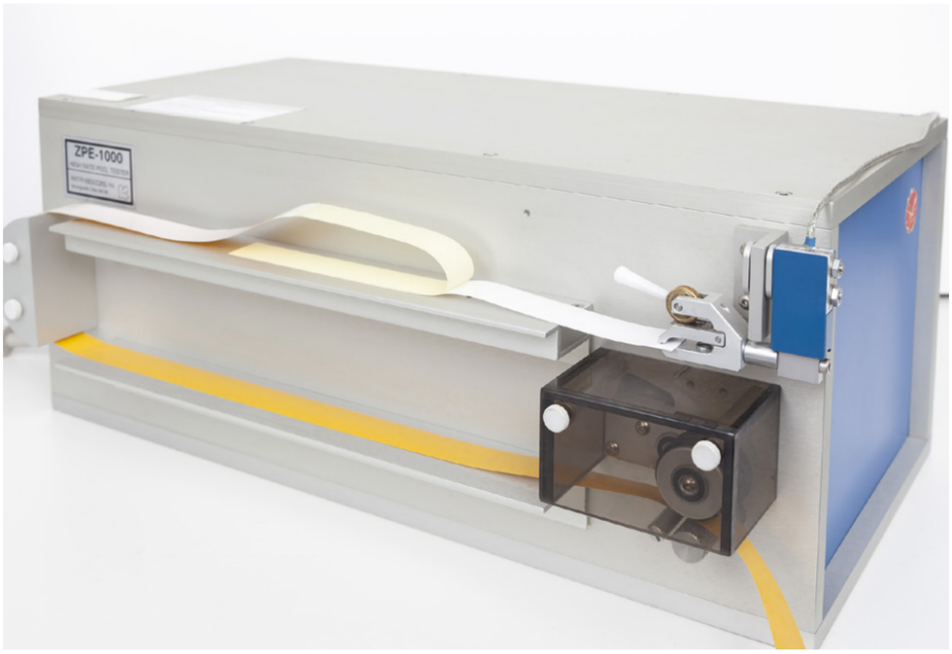


Image 9: Test method for FTM4 [15, pp. 14-15]

The tensile machine required for this testing has to possess the jaw separation range of 10-300 m per minute. The testing procedure is quite different to the low speed release testing. A part of the side of the laminate from which the other is removed is attached to the load cell jaw of the tensile machine. The side which is to be peeled off is then guided through to the roller which regulates the speed of the pull. The speed is then selected, and the test is executed. The results are presented as the average result, with the unit of centinewtons per 25mm width (cN/25mm). [15, pp. 14-15]

3.5 Dispensing tests

Willet is the machine that is used for the dispensing tests with multiple different dispensing beaks. The machine has a laser and a camera to provide continuous data on the position of the labels during dispensing in pixels. The camera also produces some standard statistics of each dispensing set and graphs which visualize the average angle of dispensing. The camera also produces a dispensing curve for each label in a set. The dispensing tests are not usually used for quality control measurements, but purely for product development. Therefore, this testing method is not standardized but is rather situational.

For each material, around a hundred dispensing tests were performed with each dispensing beak at two different speeds, 10 m/min and 30 m/min. There are four different dispensing beaks ranging from one millimeter to four millimeters. Generally, the radius of the dispensing beak affects the success rate of dispensing. As there are many repetitions, variations between the materials can be seen for example in terms of success rate of dispensing. As the sample size is large, some deviation may occur between the results. With low release force materials, large deviations may imply some zippiness in the material, but with high release force materials, there is typically more deviation due to their high release force. Lastly, the data will provide the possibility to check for inconsistencies in the dispensing curves of the labels. If it is possible to find labels with curves which provide higher and lower values during dispensing and therefore produce a back and forth graph vertically, this could be considered as zippiness.

4. RESULTS, UNCERTAINTIES AND ANALYSIS

The low and high speed release force tests were done as part of the execution of this study. However, the dispensing tests were done by an expert at the site. It was made sure that the expert was unaware of the low and high speed release results, so that they had no knowledge of which materials were defined as zippy and which not. This way the idea of trying to get certain result for some materials was avoided. All the data was received as raw data, and further processed as part of this study.

4.1 Low Speed Release

Five trials were conducted for each material at constant speed. From these test measurements, the average load and standard deviation was obtained, which can be seen in Attachment B. Low speed release force measurements were done in order to define which materials show zippiness behavior and which do not. Attachment A contains the ten raw data graphs obtained from the release pulls.

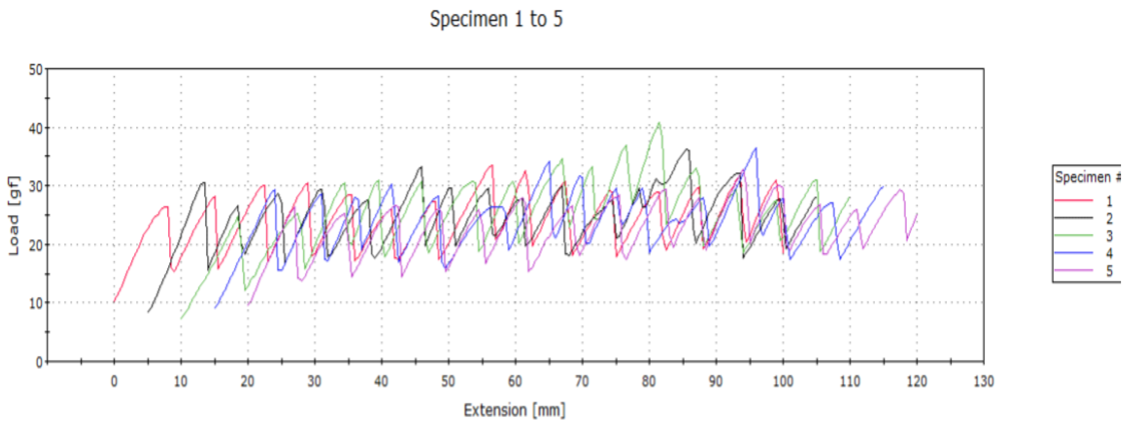


Image 10: A graph of Low Speed Release results from test material A as an example.

From all of these graphs, the level of zippiness was defined by the average maximum and minimum peak values. The unit for low speed release force measurements is typically cN/50mm but as we are only analyzing the differences of the y-axis the units of the measurements is in gram force [gf]. The deductions for each material are shown in Table 4 below.

Materials	**Level of zippiness [gf]**
Test Material A	Zippy, range 20-40
Test Material B	Zippy, range 18-35
Test Material C	Not zippy
Test Material D	Not zippy
Test Material E	Not zippy
Test Material F	Not zippy
Test Material G	Zippy, range 10-13
Test Material H	Zippy, range 40-60
Test Material I	Zippy, range 13-20
Test Material J	Zippy, range 35-60

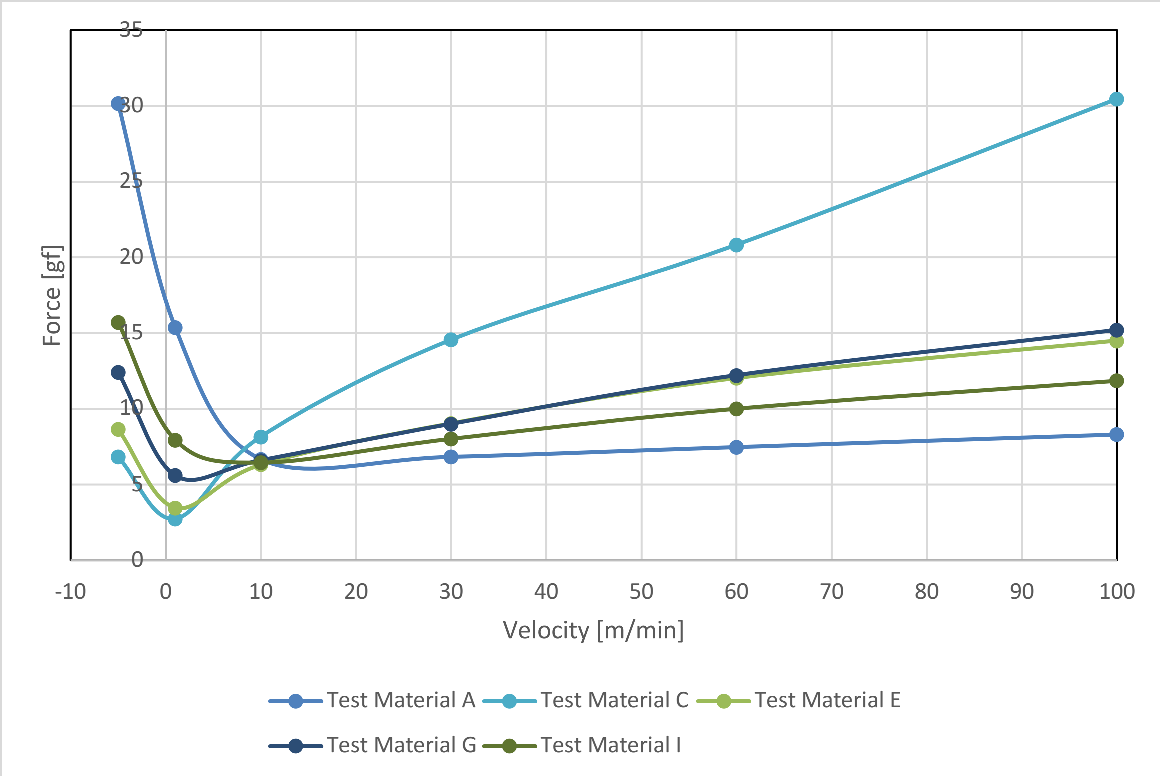
Table 4: The results of zippiness of each material from Low Speed Release pulls.

As we can see from Table 4, the release modifier greatly affects the release level of the product when measuring with Low Speed Release. Based on Table 4 the levels of zippiness can be divided into three categories: no zippiness, minor zippiness and major zippiness. Test materials C through F represent the no zippiness category, test materials G and I represent the minor zippiness and therefore test materials A, B, H and J represent major zippiness.

4.2 High Speed Release

Three trials were conducted for each material with each speed. From these test measurements, the average load and standard deviation was obtained, which can be seen in Attachment C. High speed release measurements were done, in order to understand how each material behaves at higher speeds. The results have been split into two graphs, one showing materials without release modifier and one with the materials containing release modifier.

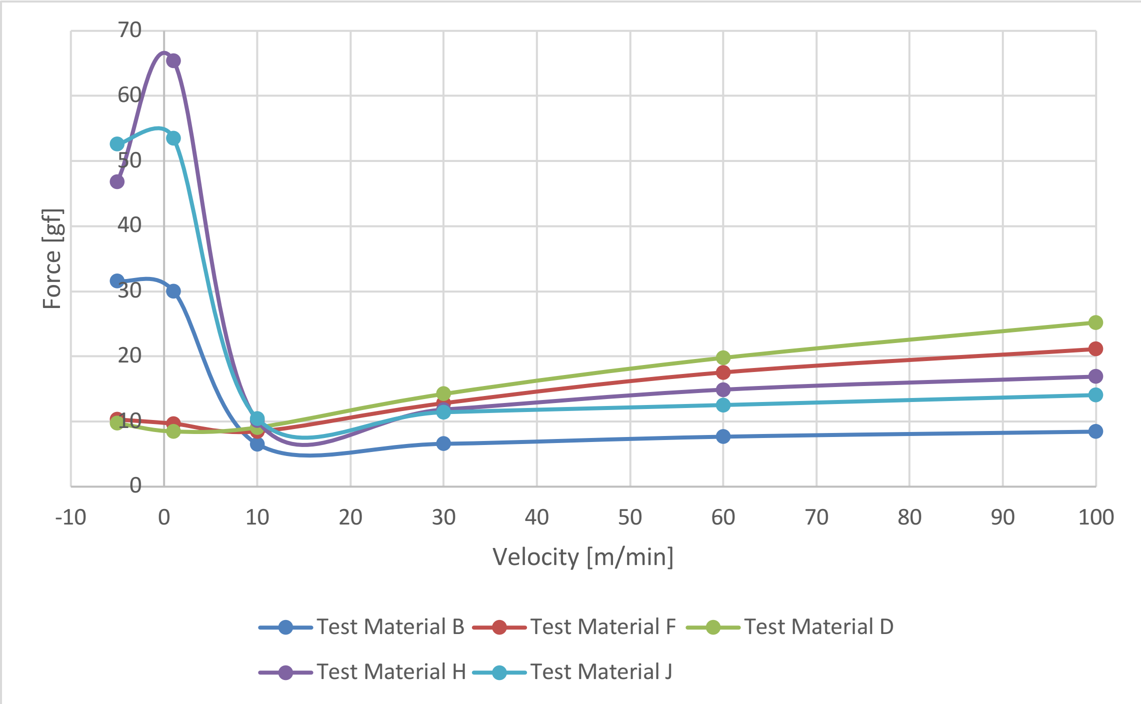
From the graphs produced from each measurement, it is impossible to distinguish which materials show zippy behavior and which not, as all the graphs show some degree of fluctuation. Therefore, the measurements can be used to define materials, which possess high release force at high speeds, and how the high release they possess can affect the dispensing results. The graphs below show the release profiles of all the materials.



Graph 1: Release profile graphs of materials with silicones containing 0% of release modifier

The graph shows the release profile of five materials. The graph uses two low speed release measurements, one done with face releasing off the backing and the other one reversed. The values received from these measurements are presented on the graph on the x-coordinate values -5 and zero. The rest of the graphs are drawn based on the high speed release measurements done with different speeds. The speeds include 10m/min, 30m/min, 60m/min and 100m/min and these are presented on the graph at those exact x-coordinates.

From graph 1, it can be observed most of the high speed measurements have been similar between the materials. It seems that test material A has a significantly higher low speed release, but the high speed release results are much lower. Test material C is the material that seems to stand out the most as its high speed results differ the most from the other materials. According to the graph it can be seen that even though test material C has the lowest results in low speed release measurements, it has the highest high speed release results. This suggests that this material can be more difficult to dispense, as at high dispensing speeds it requires a high amount of force to remove it from its backing. Lastly, test materials E, G and I behave all relatively similarly. It seems, that they all need about the same amount of force in order to release in both low and high speed release tests.

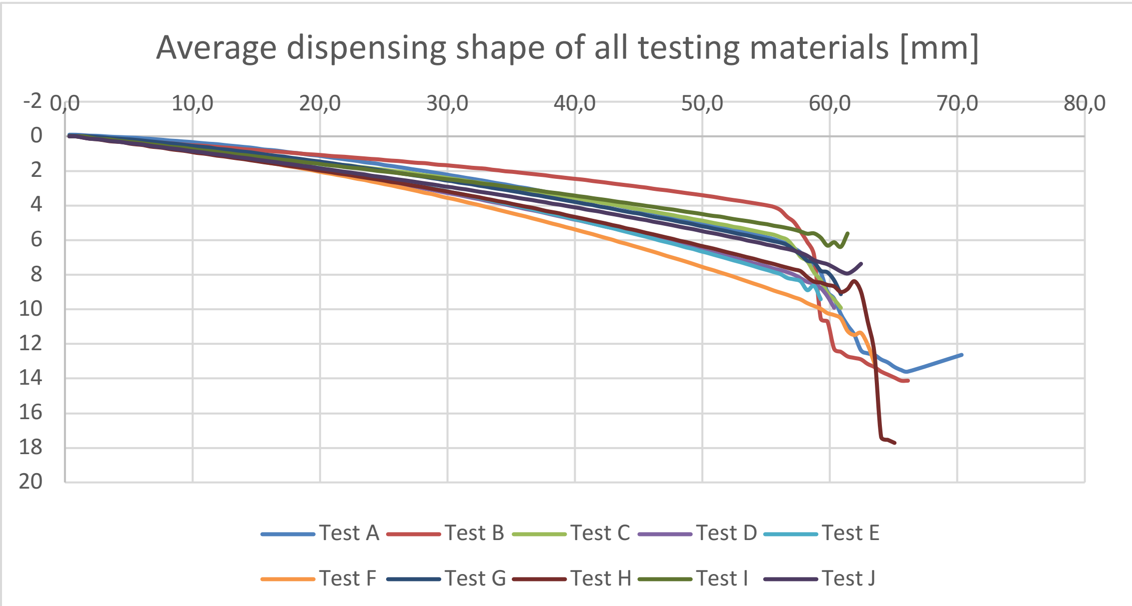


Graph 2: Release profile graphs of materials with silicones containing release modifier

As it can be observed from graph 2, it seems that all the materials have relatively similar high speed release measurements. Even though they possess different values, the way all the measurements progress when speed is increased, is similar. None of the materials stand out based on their high speed release values. However, the low speed release values have clearly reacted from the addition of release modifier, when comparing to the low speed values of graph 1. The values have significantly increased, and the basic shape of the graphs that can be seen in graph 1 have drastically changed in graph 2. From these deductions it can be defined, that the addition of release modifier mostly seems to affect the release results at low speeds.

4.3 Dispensing test results

The key test in order to find zippiness when dispensing the labels is the observing vibration of the labels. The dispensing testing was conducted with four different dispensing beaks, varying with radius sizes 1-4 millimeters. With each beak, the dispensing was done at two speeds, 10m per minute and 30m per minute, and for each material a hundred trials were conducted. The laser and camera present in the dispensing machine recorded the position of each label every 0.5 millimeters in pixels until the dispensing was completed. The data was received for each of the runs, for each speed and dispensing beak size. Based on the data it was decided that only the data from dispensing beaks with radius 1mm and 3mm were processed, as with those dispensing beaks it would be possible to get a comparison of using a very sharp beak which dispenses easily, and a duller beak which was able to still successfully dispense the material. In addition, it was illogical to use the 4mm radius beak, as it had a high failure rate, and therefore the data was not consistent and hardly comparable. From all the collected data, an average curve for each material at 10m per minute was created to show the average shape of dispensing for each material. This can be seen in graph 3. The shape and variations of each dispensing set and dispensing beak can be seen in attachment C and D.



Graph 3: Average dispensing shape for all the ten testing materials at speed 10m/min

By observing graph 3, it can be assumed that all the materials follow a linear module during their dispensing. An average slope was calculated for the materials using the x- and y-coordinates of the system. It was defined that as the graph progresses approximately 10 pixels in horizontal direction, the vertical change of the curve is 1 pixel. This means that when the laser and camera track the position of the labels every 3 pixels, the vertical change is around 0.3 pixels. Therefore, it can be assumed that every three measurements, the labels move down one pixel or less in vertical direction. With these calculations it can be ruled, that all fluctuations during dispensing that range from zero to one are considered to be normal in terms of dispensing behavior. After this ruling it was possible to examine all the dispensing runs for each material and calculate how each 3-pixel measurement compared to the previous measurement. If the difference was within the defined range, the material was behaving normally at that point. If not, the label had been moving more than normal in positive or negative vertical direction and therefore causing some vibration during dispensing. With this information, it was possible to outline the number of vibrations of each one hundred runs, and therefore get a percentage of how much vibrations occurred within each set of dispensing. Table 5 shows the obtained percentages of irregular vibrations from the sets with the 1mm radius beak at the defined two speeds.

Test Materials	Percentage of vibrations at speed 10m/min [%]	Percentage of vibrations at speed 30m/min [%]
Test Material A	0.26	0.23
Test Material B	0.23	0.05
Test Material C	0.04	0.02
Test Material D	0.33	0.01
Test Material E	0.04	0.02
Test Material F	0.03	0.00
Test Material G	0.14	0.04
Test Material H	0.04	0.00
Test Material I	0.06	0.00
Test Material J	0.01	0.04

Table 5: The results of dispensing tests measuring irregular vibrations in percentages with 1mm radius beak

When comparing the percentage of the amount of irregular vibrations, a general behavior of all materials can be observed. Based on the data it seems that as the dispensing speed increases, the amount of irregular vibrations decreases significantly. For example, with test material D out of all movement in all the repetitions at speed 10m/min, 0.33 percent of the movement is irregular behavior. However, as the dispensing speed is increased to 30m/min, the percentage of irregular behavior decreases drastically to 0.01. Similar behavior can be observed from nearly all of the testing materials. As previously mentioned, there are only five separate recipes for the test materials, and the rest of them only differ by the percentage of release modifier used. Therefore, for example recipes of materials A and B are the same besides this factor, and therefore comparable. In table 5, the big differences of vibration percentages at speed 10m/min in such pairings are with test material pairs C and D, and G and H. In materials C and D, it seems that the irregular behavior increases by the addition of release modifier, but with the other material pair G and H, it is the opposite. However, this cannot be seen in the higher speed as the values are much closer to each other.

Lastly, from the data presented in table 5 alone, it is impossible to draw conclusions whether zippiness affects dispensing, as the materials that were defined as zippy do not show significantly different behavior when compared to the other materials. In addition, the percentage values of this irregular vibrations are very small, meaning that not many vibrations occur during dispensing. Therefore, it can be said, that this amount of irregular vibrations does not significantly affect the dispensing process of the labels.

The dispensing tests were also done with a duller beak in order to investigate whether this would further contribute to the presence of zippiness. The results are shown in table 6 below.

Test Materials	Percentage of vibrations at speed 10m/min [%]	Percentage of vibrations at speed 30m/min [%]
Test Material A	4.14	3.57
Test Material B	5.00	1.40
Test Material C	11.26	17.05
Test Material D	20.94	18.05
Test Material E	6.56	6.43
Test Material F	12.52	11.97
Test Material G	3.92	3.54
Test Material H	19.72	11.88
Test Material I	6.85	4.24
Test Material J	20.21	6.94

Table 6: The results of dispensing tests measuring irregular vibrations in percentages with 3mm radius beak

Compared to table 5, table 6 provides much larger values in terms of how much irregular vibrations occur during the dispensing of the materials. All the materials show increased irregular behavior in both observed speeds. This increase could indicate that the radius of the dispensing beak has an effect on the irregular behavior of the labels. When looking at the material pairs, a clear pattern can be observed. It seems that the second material of each pair has a higher percentage for irregular behavior. This is especially visible at speed 10m/min, but can be also seen to some extent at speed 30m/min. This pattern suggests that as release modifier is added to the material, the irregular behavior also increases. This further indicates that the level of release force has an effect on the irregular behavior of labels during dispensing, as within the pairs there is a significant difference in the release results of the materials. It is known that high release values can cause more deviation between the dispensing results, and it seems that this is potentially the cause for the difference in behavior.

The difference of irregular vibrations between the pairs is not as extensive at 30m/min, but the materials still seem to behave similarly as at speed 10m/min with one exception. It can be detected that that material pair A and B do not follow this behavior at speed 30m/min. The behavior of this material pair cannot be explained by their measured low and high speed release tests either, as according to those test results, they have obtained similar results in all testing. In addition, this difference in behavior when compared to the other materials, cannot be explained by the addition of release modifier to material B either, as all pairings had one material that had an addition of the release modifier. Therefore, it can be assumed that this difference in behavior can only be explained by the choice of polymer in the release coating, and the interactions that it creates. This is however something, that cannot be determined, as there are no records of previous testing available for these materials.

Lastly, it is hard to observe any signs of zippiness based on these test results. Clearly there are some deviations between the results, but when analyzing the data, the effect of high release on many of the materials has to be taken into account. Furthermore, some of the materials that were defined as not zippy due to their clear low speed release profile, showed some of the worst behavior during dispensing causing high percentages or irregular vibrations. Therefore, it is not possible to analyze whether the behavior in other materials is caused by zippiness either. Based on these results, it is possible that zippiness is one factor of many that causes the labels to vibrate during dispensing, but it seems to not be the main factor causing it.

5. CONCLUSIONS

Overall, the main focus of this study was to determine whether zippiness has an effect on the dispensing of labels. Zippiness can be defined as the irregular behavior of the material during release testing, as it causes continuous peaks to the release graphs. For this study, ten test materials were chosen, which all had the same face material, adhesive and backing. Therefore, the only differing factor between the materials was the release coating recipes. Five different recipes were chosen, and two test materials represented each recipe. One test material of each recipe was produced without a release modifier, whereas the other material had release modifier. This way, it was possible to take into account also the factor of release modifier when defining which materials showed zippiness and which not. After these decisions, the materials were produced and tested upon in many ways. This study was not based on prior knowledge, as the phenomenon has not been tested before. Therefore, there were no assumptions of what the results may be.

The zippiness of the materials was defined by low speed release tests, as they best showed the phenomenon of zippiness. In addition, high speed release tests were done to achieve the full release profile of each test material. The testing showed different level of zippiness and four materials, which did not show any signs of zippiness. This is knowledge that was a requirement for the dispensing tests, as comparison was possible with these measurements.

The dispensing tests conducted by a laboratory expert showed some deviation between the results, especially when comparing the results of the two different dispensing beak sizes of 1mm and 3mm radiuses. With the 1mm radius beak, the differences were small, and the amount of irregular vibrations was insignificant, as the value was under 1% for all the materials at both speeds. With such results it was impossible to determine if zippiness played any part in the small irregularities or not. Due to this the 3mm radius measurements were analyzed and compared to the 1mm radius measurements. Based on all the results, it seems that the zippiness is most probably caused by the polymer and its interactions in the release coating recipe.

The research question of this study was does zippiness affect the dispensing of labels. With these investigations it seems that zippiness of the material does not correlate to poor dispensing of labels. Even though there was some clear deviation and unnecessary movements of the labels during dispensing tests, the data analyzed did not clearly show that the irregular behavior was due to zippiness. In addition, the dispensing tests purely tested the movements and angles of the labels when they are dispensed off of different beaks. However, the testing did not take into account the substrate that the labels in normal conditions would be applied to. In those instances, the label would come off the beak only around 5-10 millimeters, whereas in the testing, the labels came off the beak completely. In addition, dispensing is typically done at higher speeds than 10m/min or 30m/min, so in order to truly see whether zippiness occurs during dispensing, testing at higher speeds are required. In order to fully understand if zippiness affects dispensing, some further testing would be needed, with wider range of materials, dispensing speeds and dispensing beaks. This way more data could be gathered.

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ATTACHMENT A

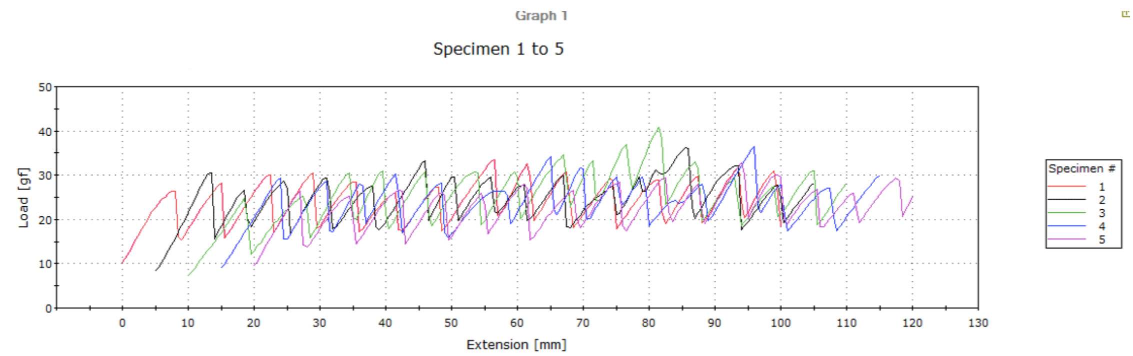


Image 11: Low speed release test of Test material A

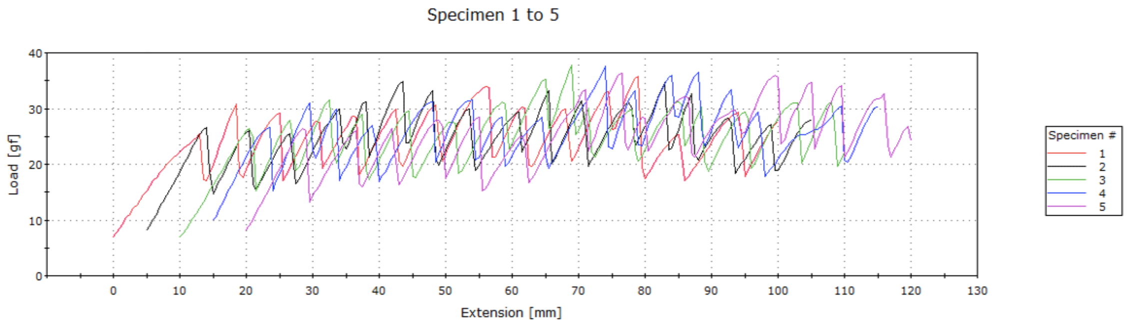


Image 7: Low speed release test of Test material B

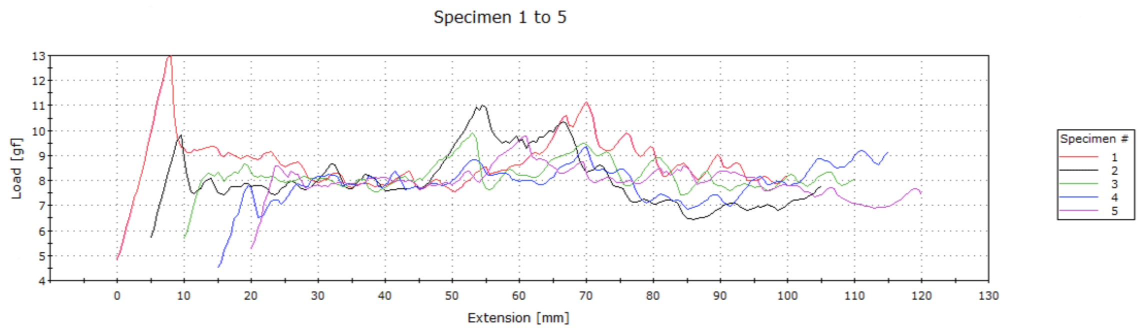


Image 8: Low speed release test of Test material C

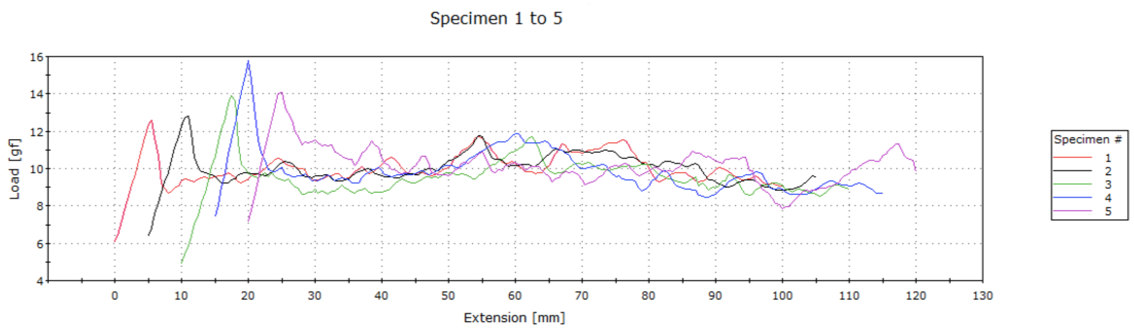


Image 9: Low speed release test of Test material D

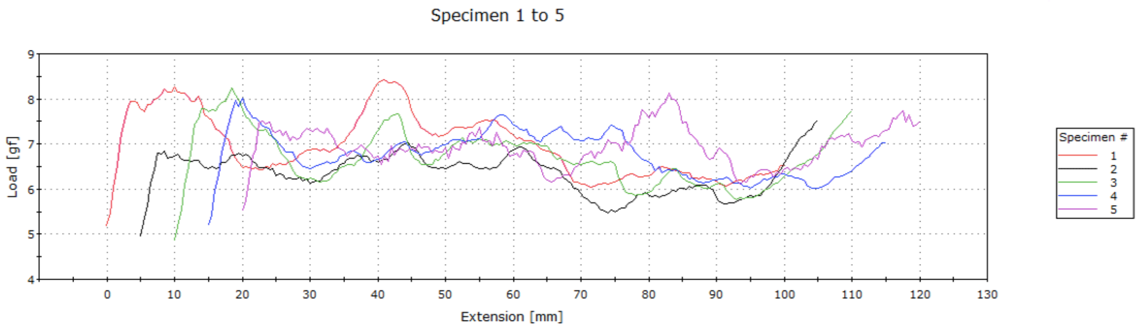


Image 10: Low speed release test of Test material E

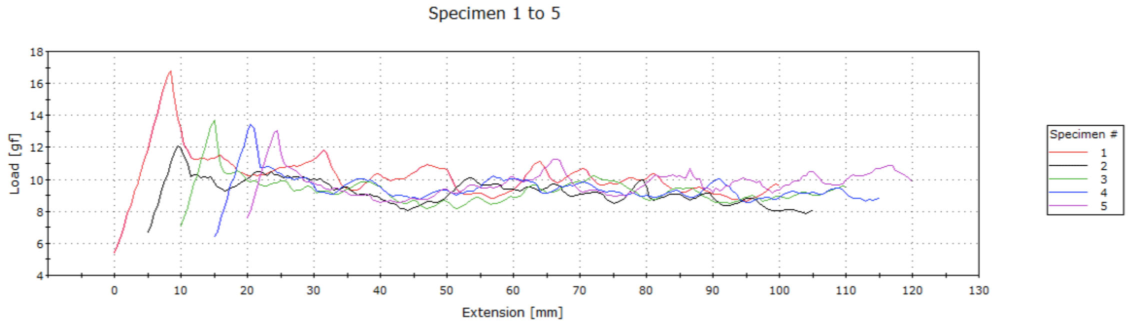


Image 11: Low speed release test of Test material F

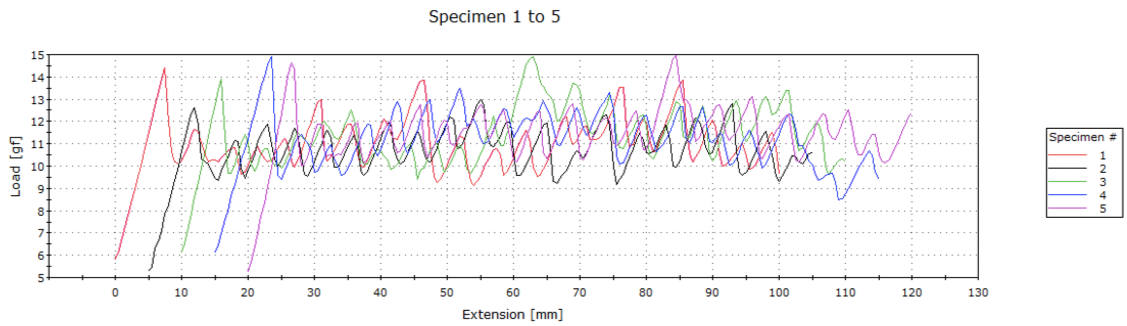


Image 12: Low speed release test of Test material G

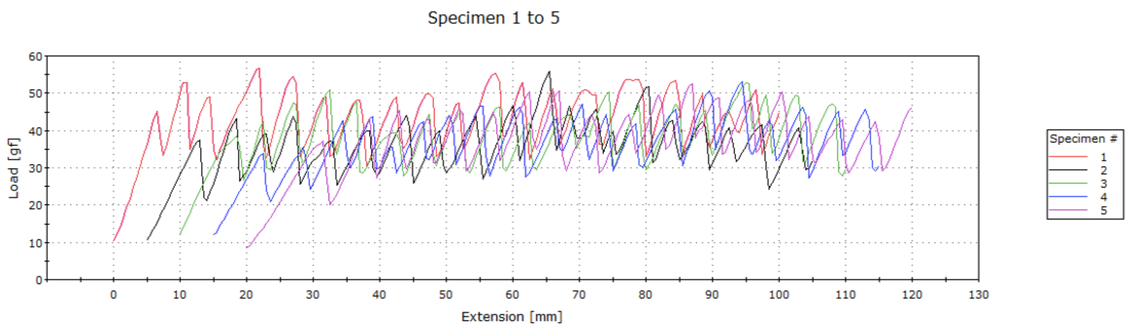


Image 13: Low speed release test of Test material H

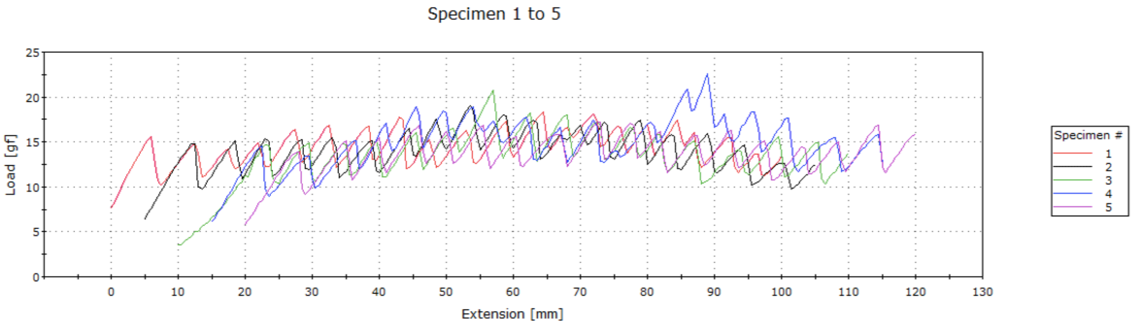


Image 14: Low speed release test of Test material I

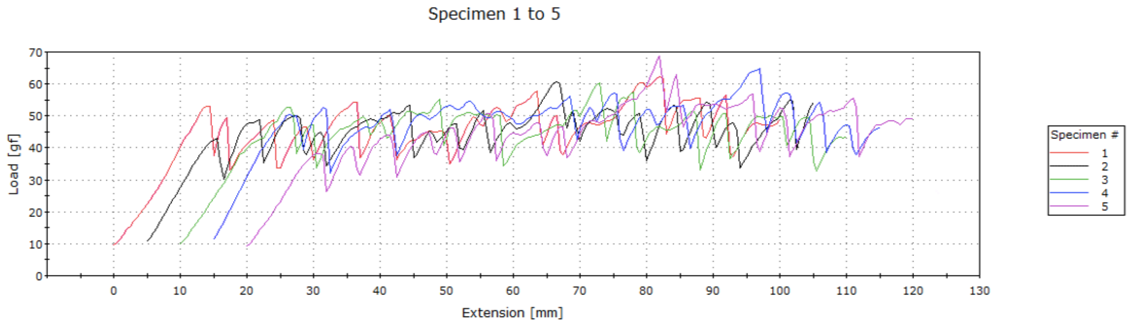


Image 15: Low speed release test of Test material J

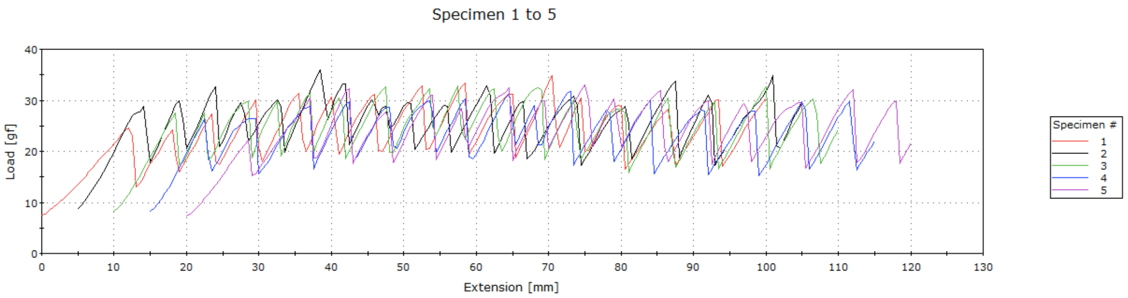


Image 16: Reverse low speed release test of Test material A

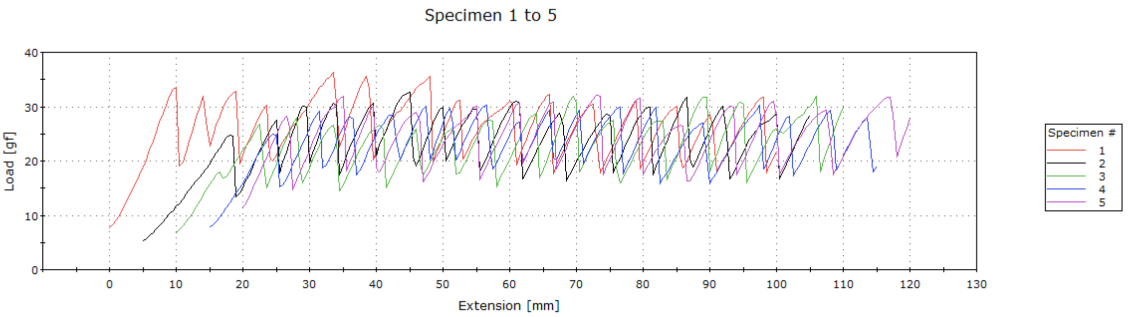


Image 17: Reverse low speed release test of Test material B

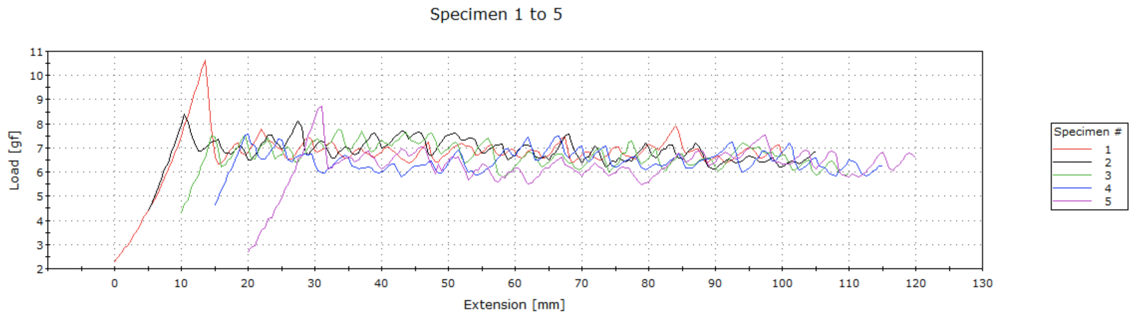


Image 18: Reverse low speed release test of Test material C

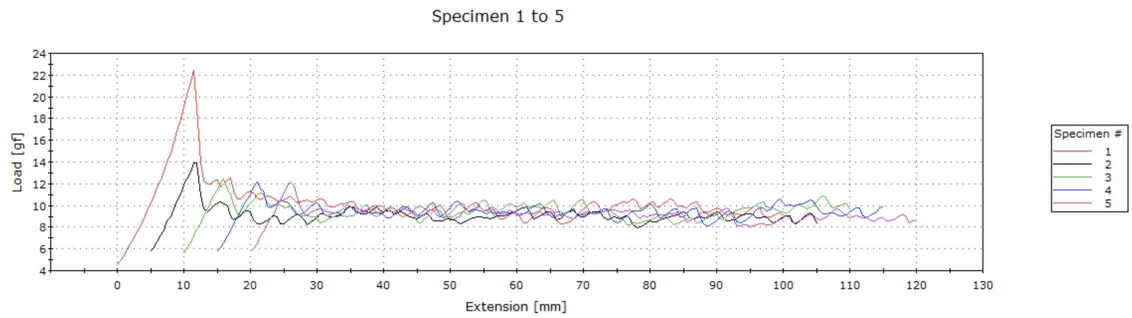


Image 19: Reverse low speed release test of Test material D

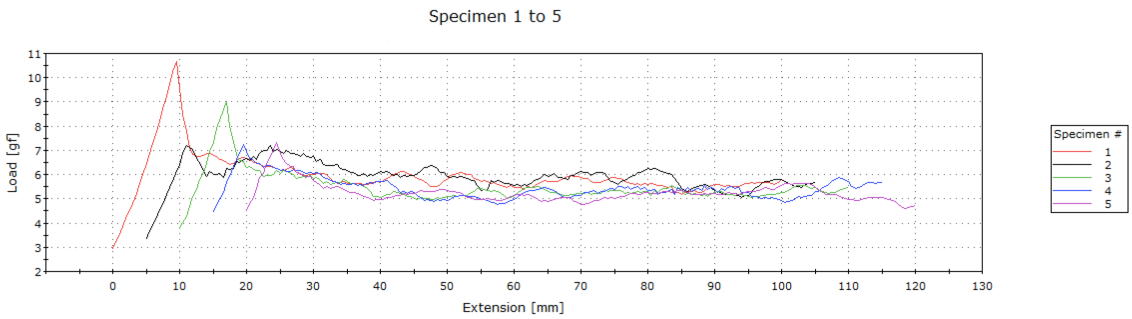


Image 20: Reverse low speed release test of Test material E

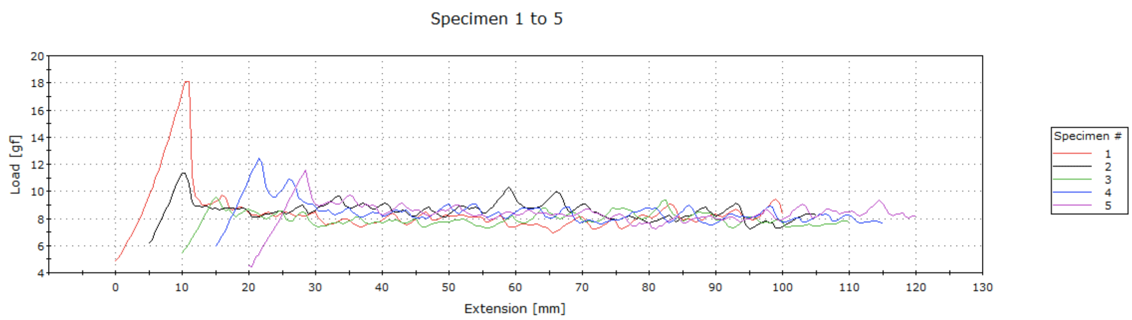


Image 21: Reverse low speed release test of Test material F

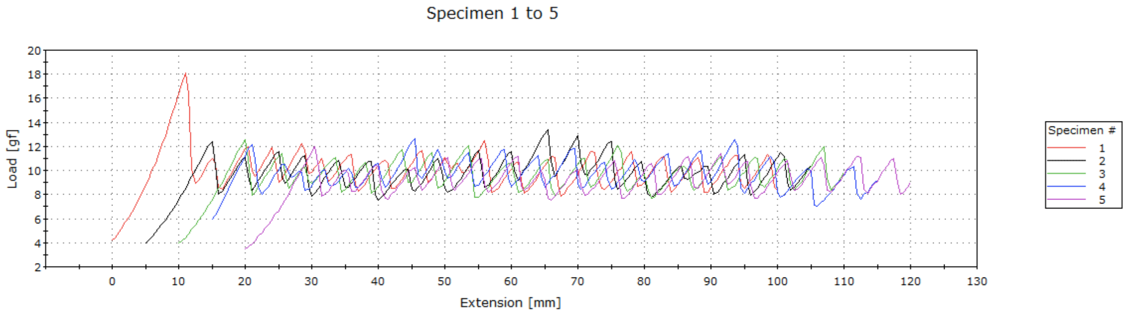


Image 22: Reverse low speed release test of Test material G

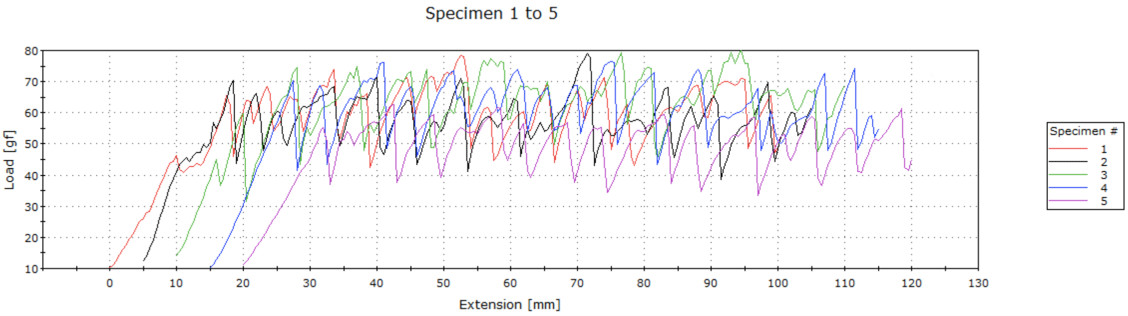


Image 23: Reverse low speed release test of Test material H

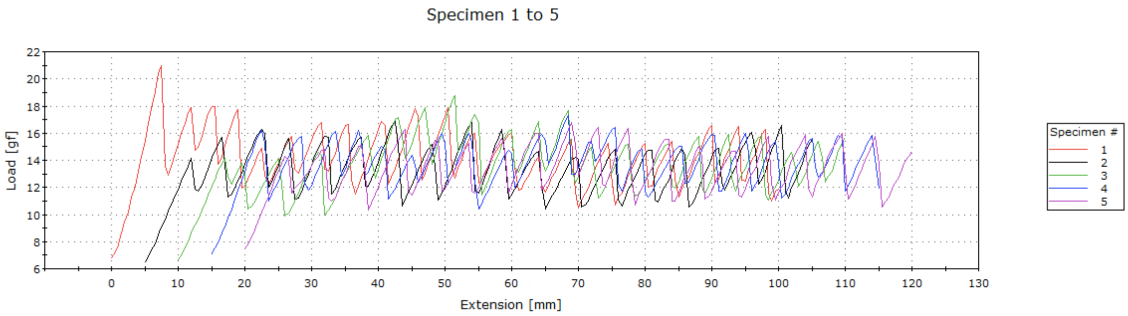


Image 24: Reverse low speed release test of Test material I

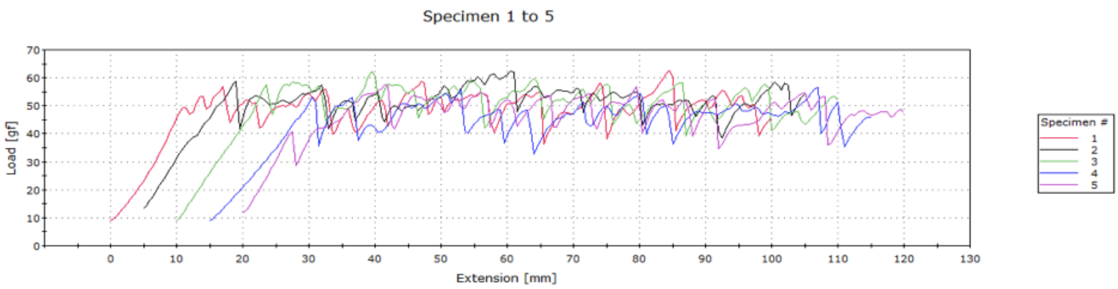


Image 25: Reverse low speed release test of Test material J

ATTACHMENT B

Table 1: Low speed release measurements at 300mm/min speed

Release Coating	Average Load [gf]	Standard deviation
Test Material A	30	1.64
Test Material B	32	0.79
Test Material C	9	0.36
Test Material D	10	0.30
Test Material E	7	0.31
Test Material F	10	0.47
Test Material G	12	0.34
Test Material H	47	2.58
Test Material I	16	2.0
Test Material J	53	1.27

Table 2: Reverse low speed release measurements at 300mm/min speed

Release Coating	Average Load [gf]	Standard deviation
Test Material A	31	0.76
Test Material B	30	1.52
Test Material C	7	0.22
Test Material D	10	0.33
Test Material E	6	0.34
Test Material F	8	0.33
Test Material G	11	0.27
Test Material H	65	5.99
Test Material I	16	0.45
Test Material J	54	2.21

ATTACHMENT C

Table 4: High speed release measurements at 10m/min speed

Release Coating	Average Load [gf]	Standard deviation
Test Material A	7	0.28
Test Material B	7	0.17
Test Material C	6	0.10
Test Material D	8	0.15
Test Material E	8	0.12
Test Material F	9	0.17
Test Material G	7	0.10
Test Material H	10	0.04
Test Material I	6	0.08
Test Material J	10	0.20

Table 6: High speed release measurements at 30m/min speed

Release Coating	Average Load [gf]	Standard deviation
Test Material A	7	0.13
Test Material B	7	0.17
Test Material C	9	0.10
Test Material D	13	0.51
Test Material E	15	0.49
Test Material F	14	0.39
Test Material G	9	0.08
Test Material H	12	0.70
Test Material I	8	0.19
Test Material J	11	0.62

Table 7: High speed release measurements at 60m/min speed

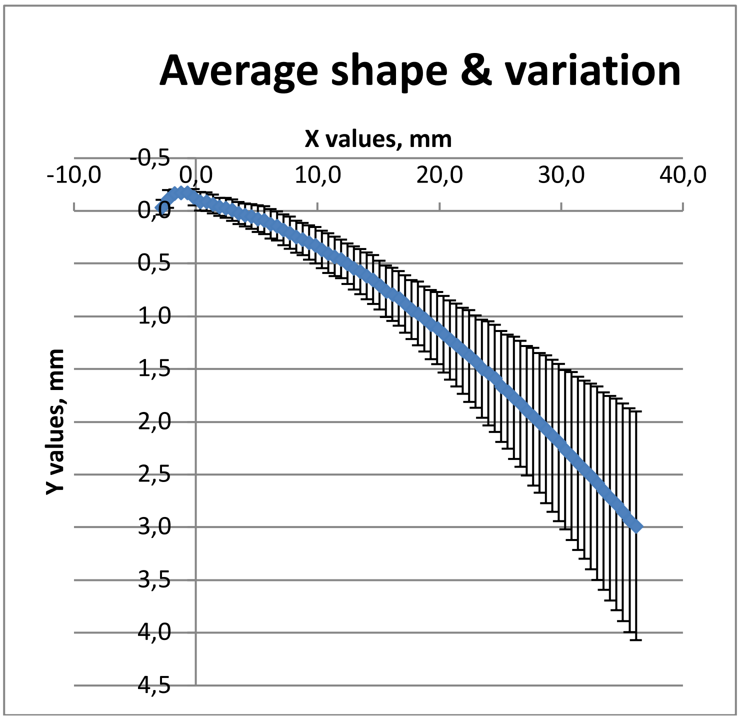
Release Coating	Average Load [gf]	Standard deviation
Test Material A	7	0.34
Test Material B	8	0.11
Test Material C	12	0.62
Test Material D	18	0.44
Test Material E	21	0.66
Test Material F	20	0.49
Test Material G	12	0.16
Test Material H	15	0.09
Test Material I	10	0.25
Test Material J	13	0.42

Table 8: High speed release measurements at 100m/min speed

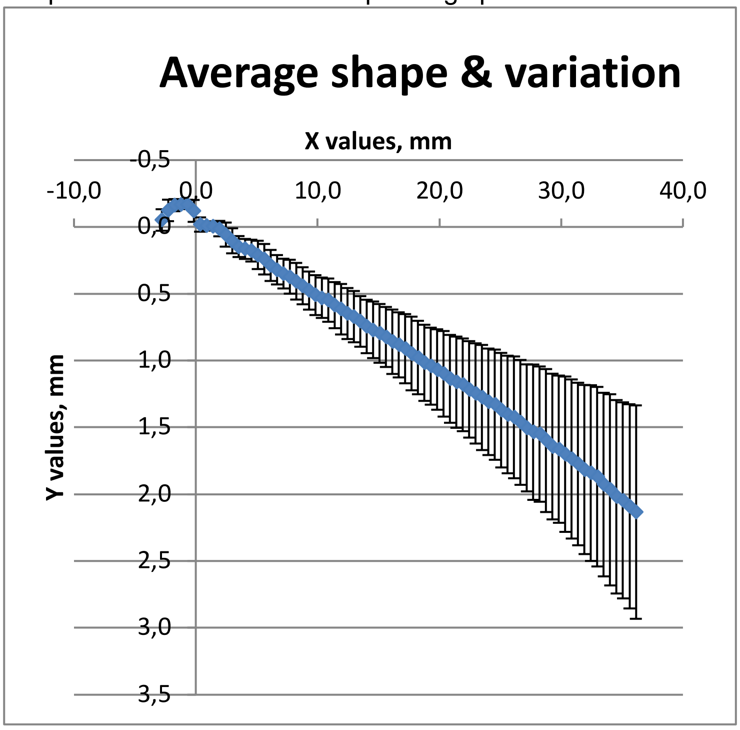
Release Coating	Average Load [gf]	Standard deviation
Test Material A	8	0.27
Test Material B	8	0.12
Test Material C	15	0.15
Test Material D	21	0.52
Test Material E	30	0.89
Test Material F	25	1.04
Test Material G	15	0.28
Test Material H	17	0.19
Test Material I	12	0.16
Test Material J	14	0.66

ATTACHMENT D

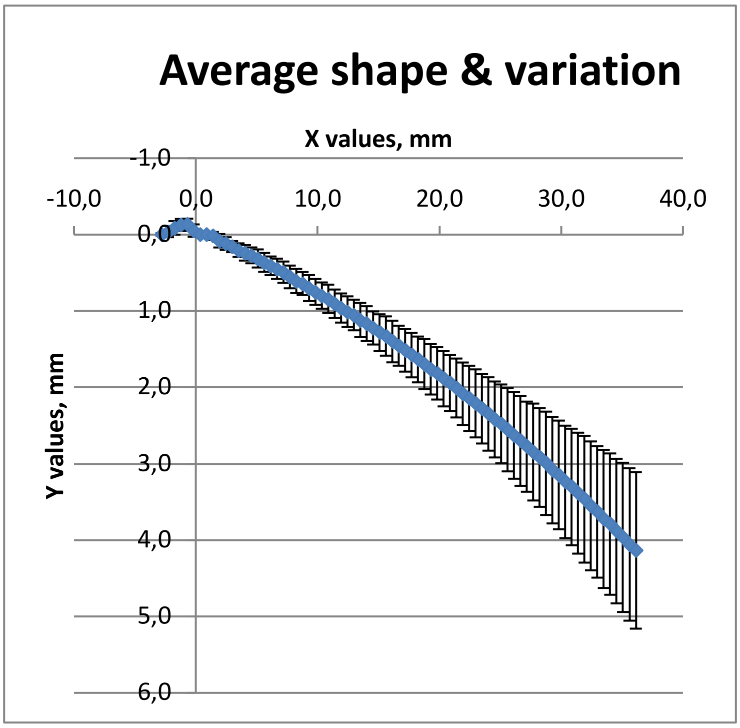
Average shape and variation graphs with 1mm dispensing beak



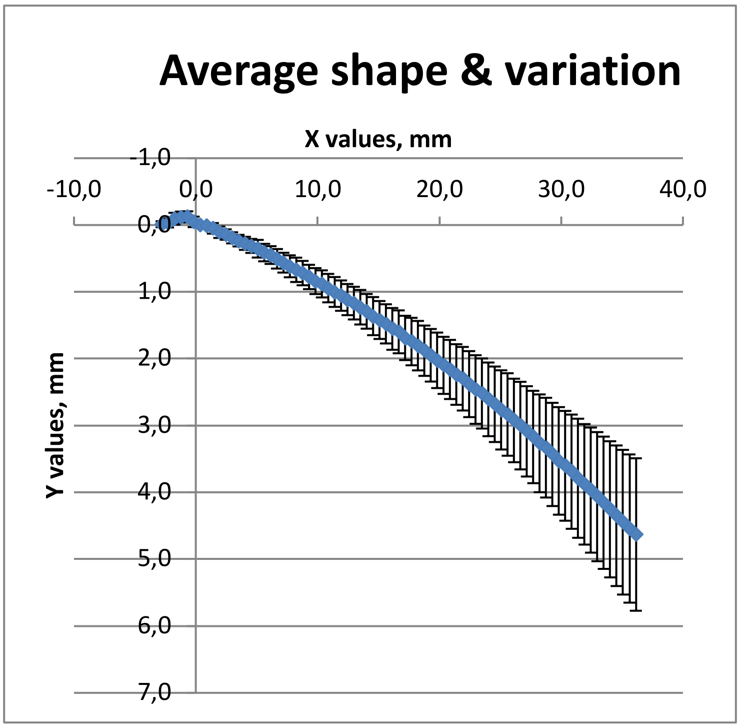
Graph 1: Test material A at dispensing speed 10m/min



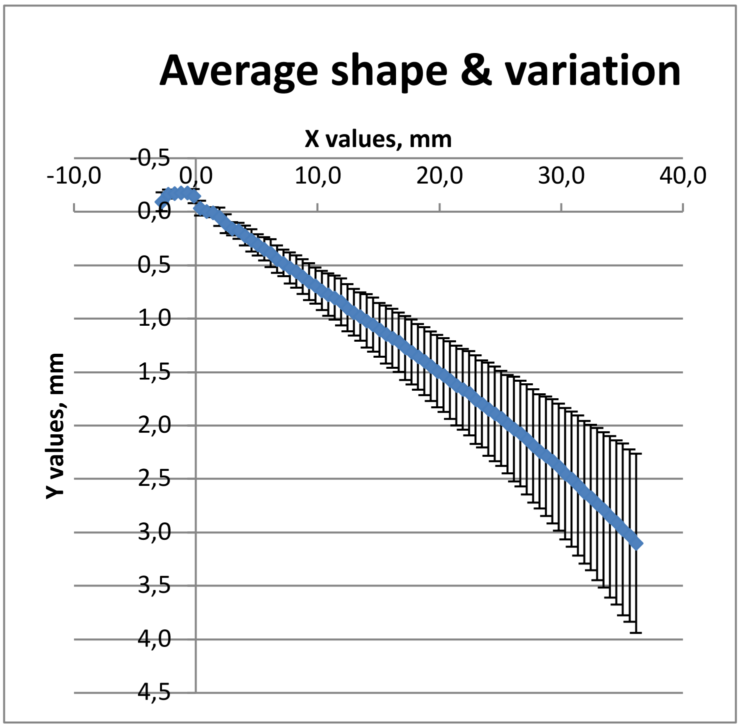
Graph 2: Test material B at dispensing speed 10m/min



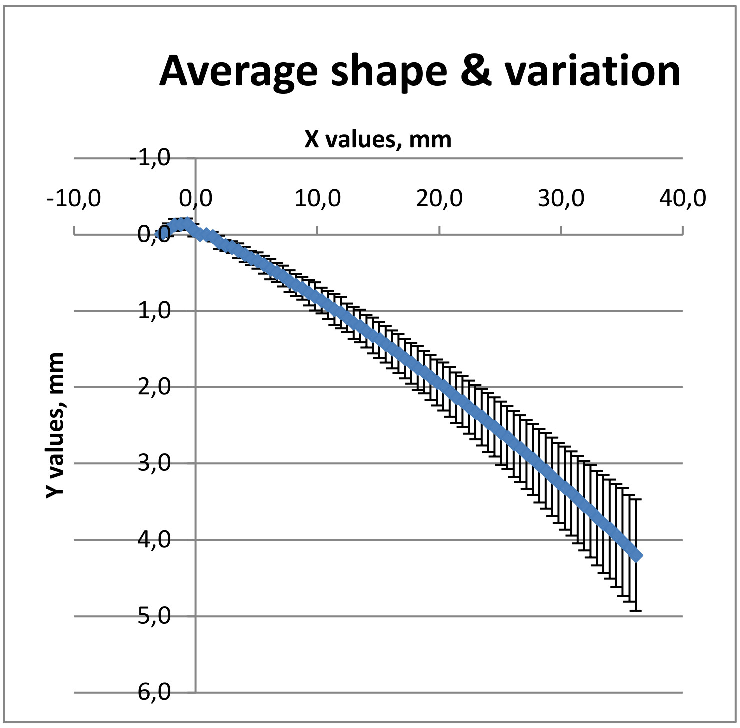
Graph 3: Test material C at dispensing speed 10m/min



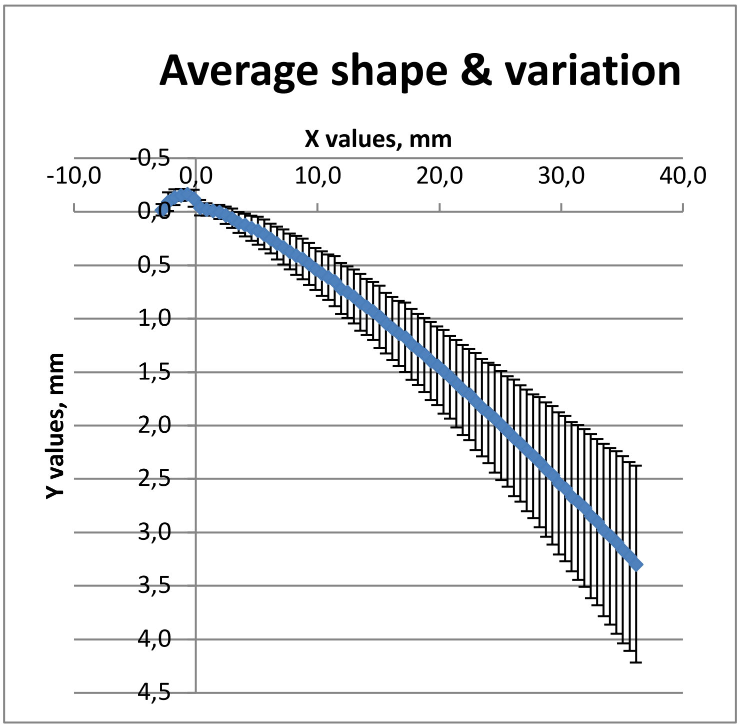
Graph 4: Test material D at dispensing speed 10m/min



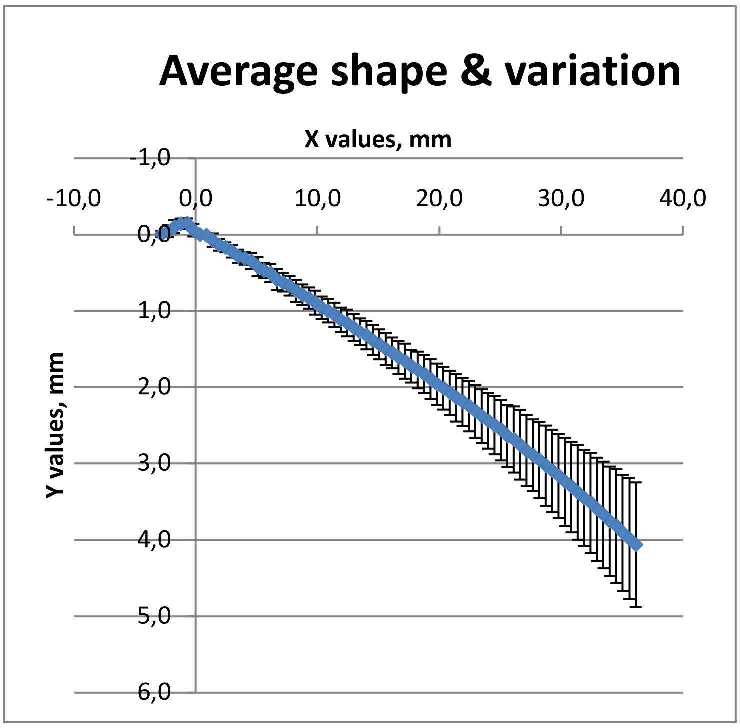
Graph 5: Test material E at dispensing speed 10m/min



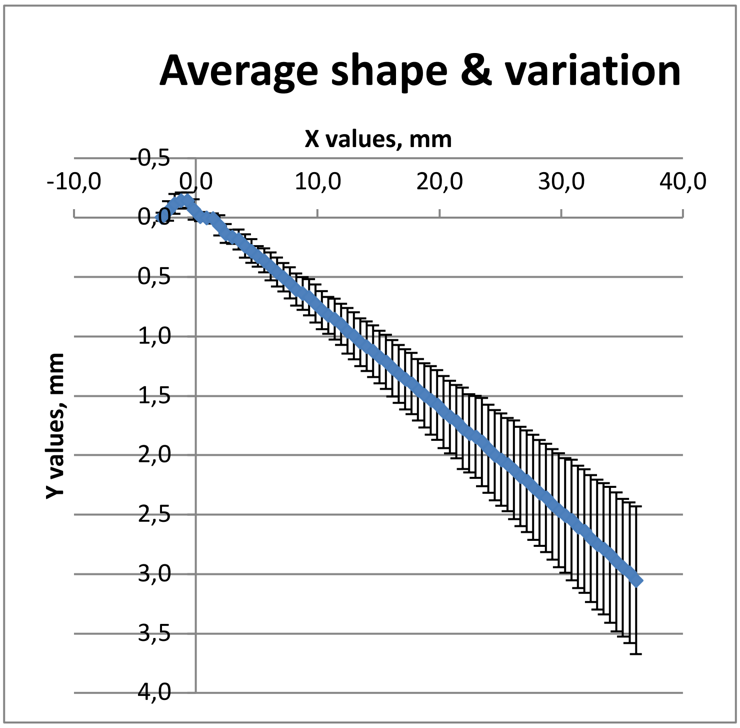
Graph 6: Test material F at dispensing speed 10m/min



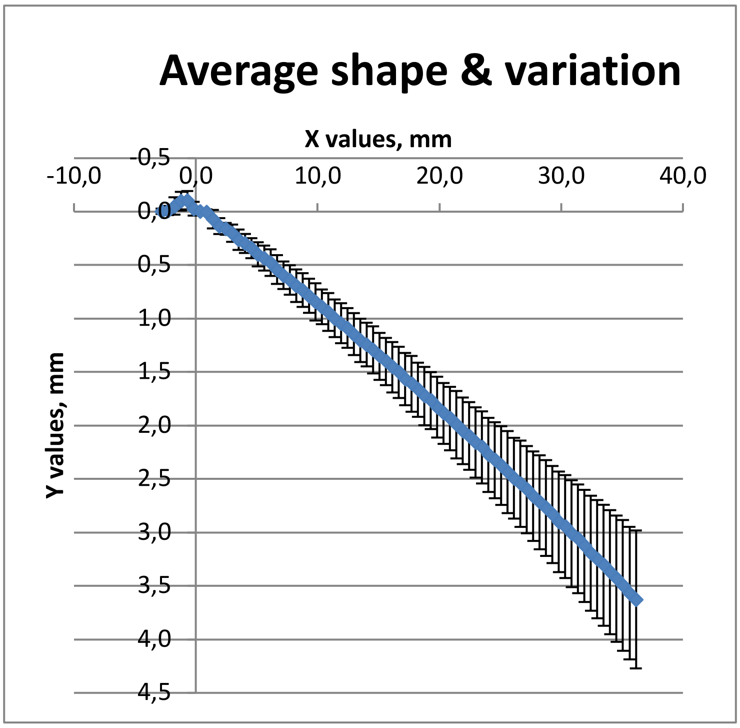
Graph 7: Test material G at dispensing speed 10m/min



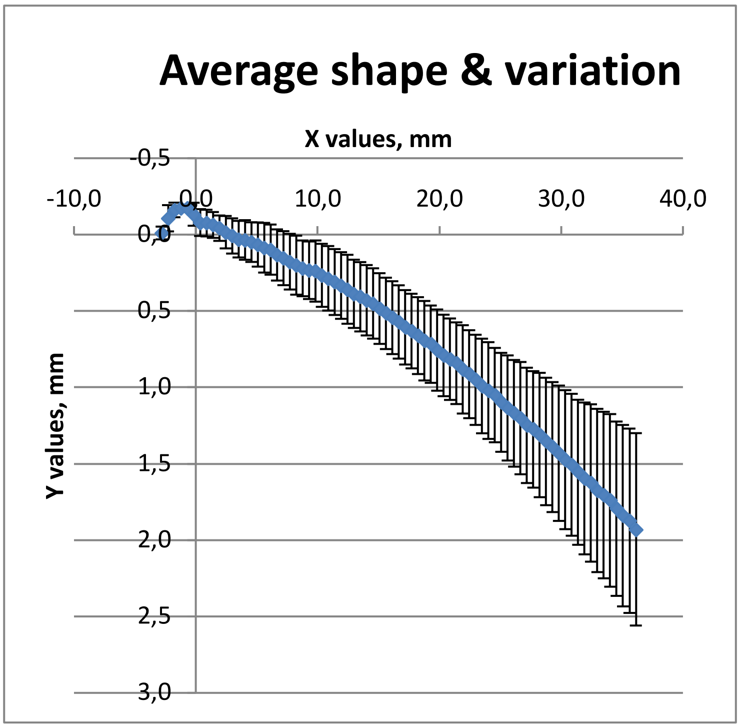
Graph 8: Test material H at dispensing speed 10m/min



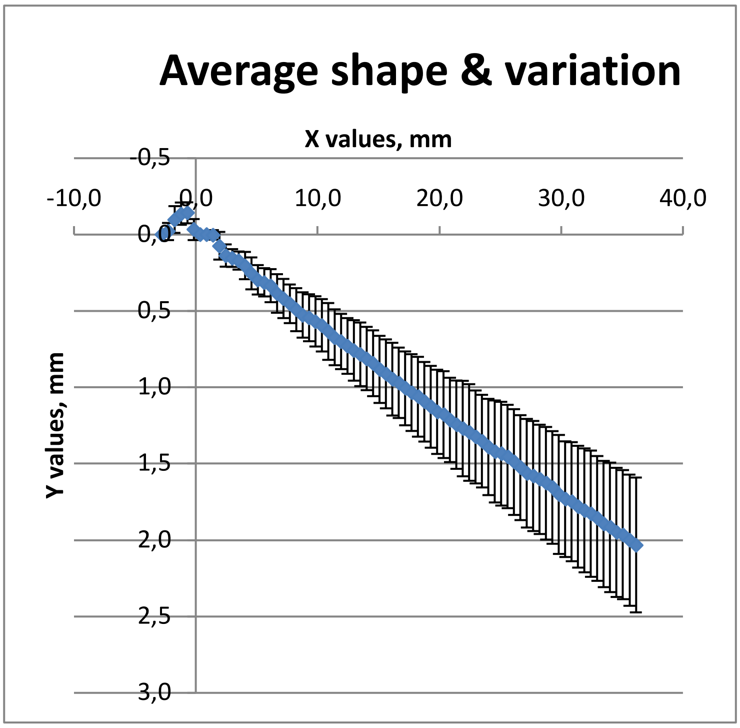
Graph 9: Test material I at dispensing speed 10m/min



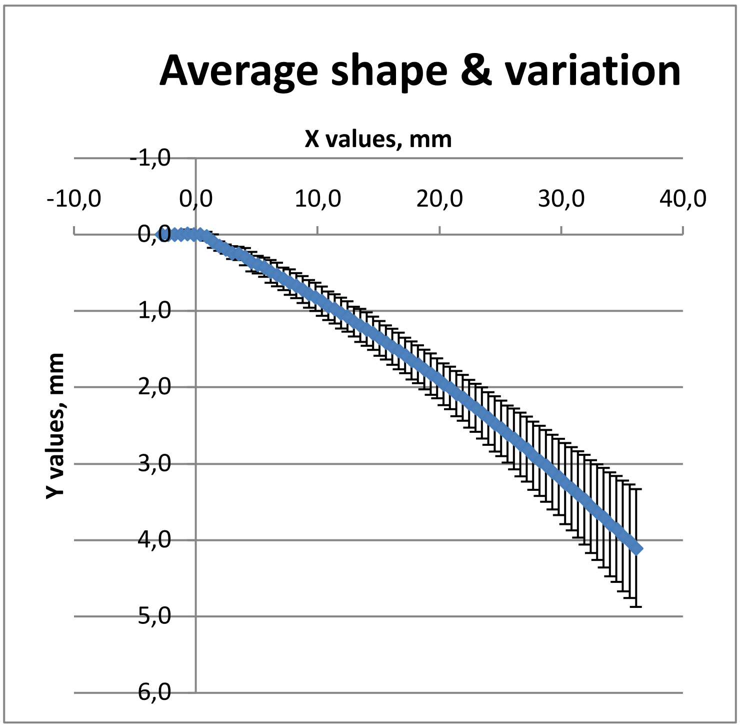
Graph 10: Test material J at dispensing speed 10m/min



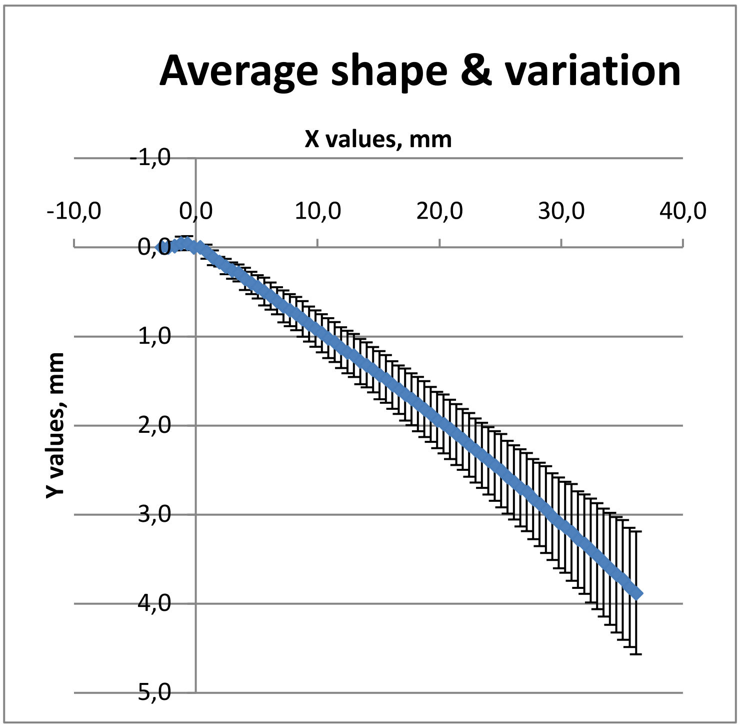
Graph 11: Test material A at dispensing speed 30m/min



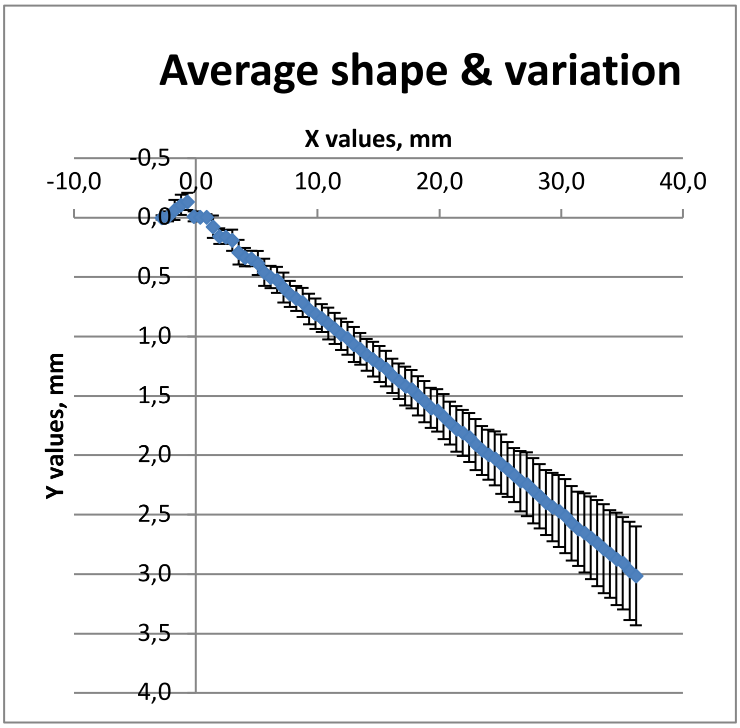
Graph 12: Test material B at dispensing speed 30m/min



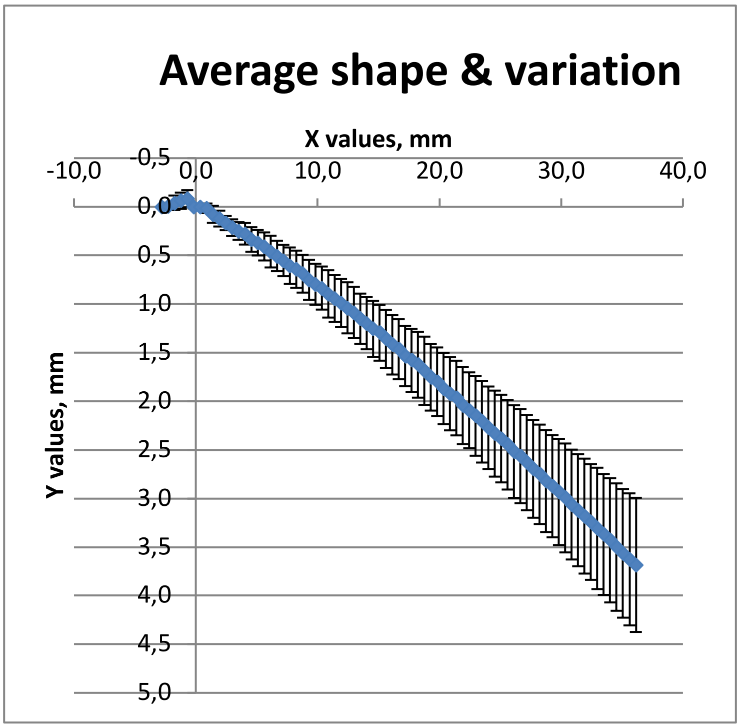
Graph 13: Test material C at dispensing speed 30m/min



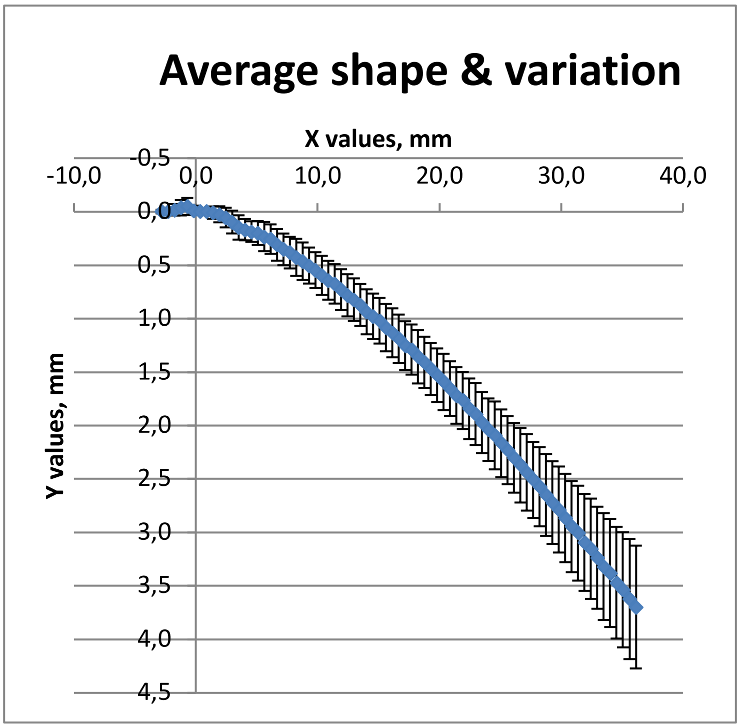
Graph 14: Test material D at dispensing speed 30m/min



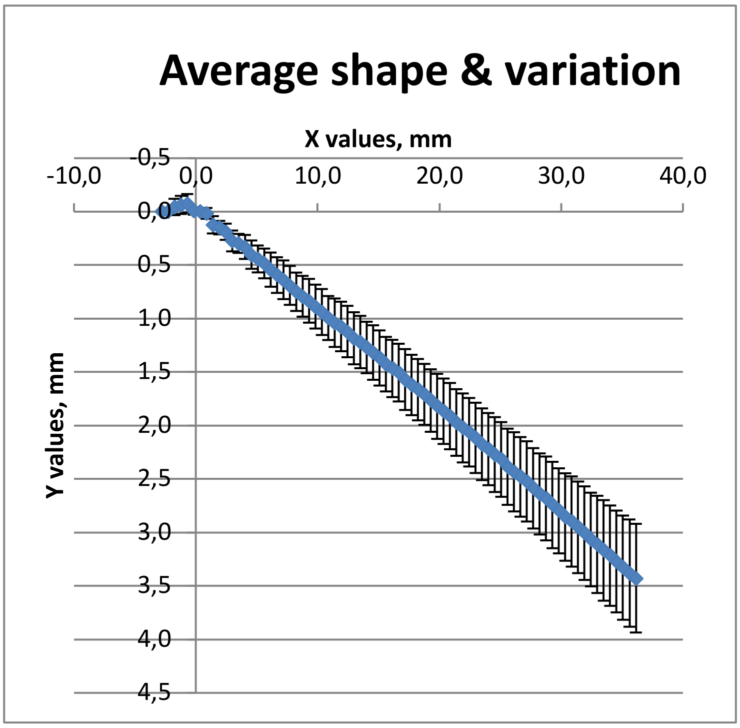
Graph 15: Test material E at dispensing speed 30m/min



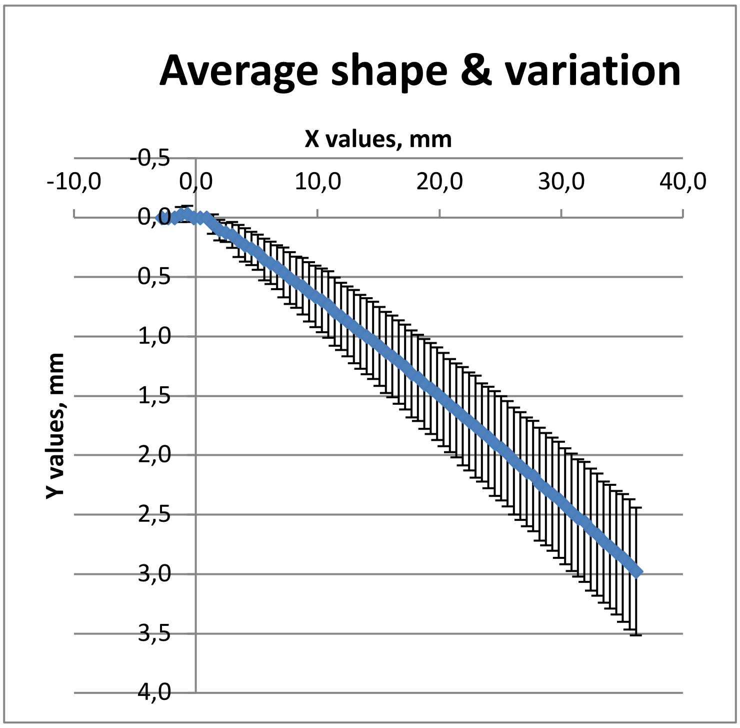
Graph 16: Test material F at dispensing speed 30m/min



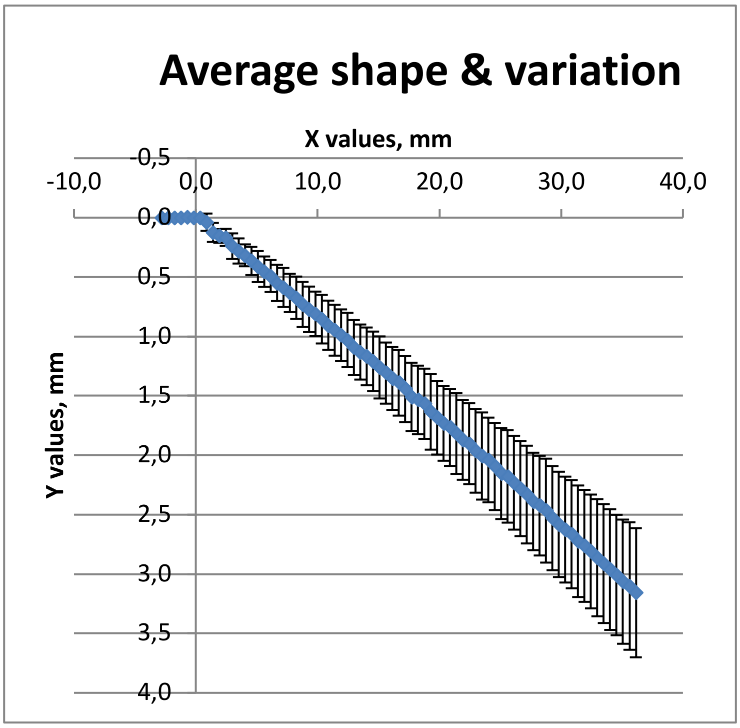
Graph 17: Test material G at dispensing speed 30m/min



Graph 18: Test material H at dispensing speed 30m/min



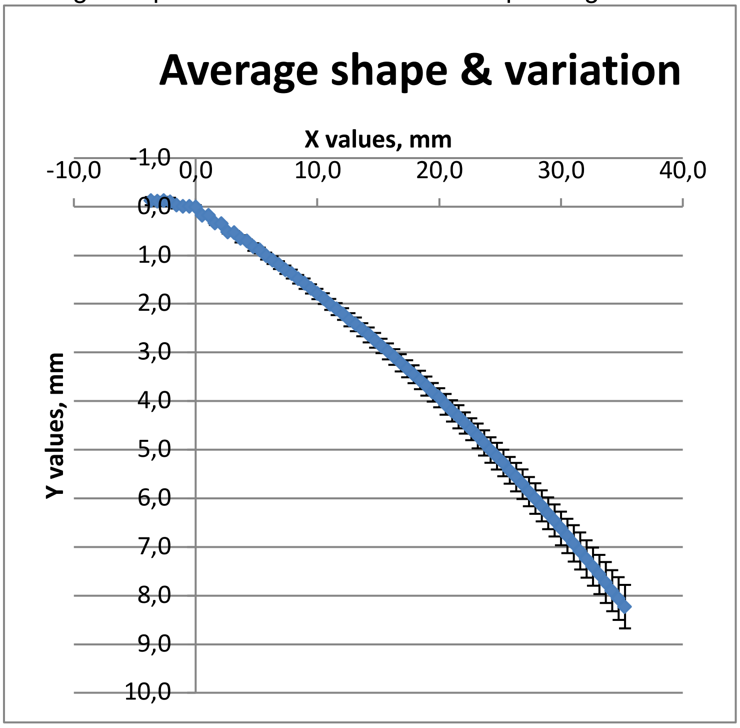
Graph 19: Test material I at dispensing speed 30m/min



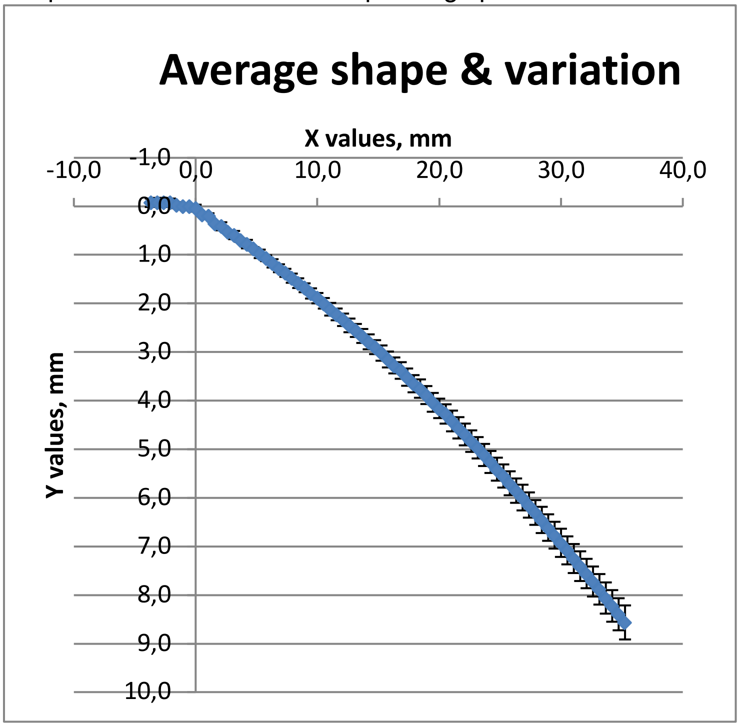
Graph 20: Test material J at dispensing speed 30m/min

ATTACHMENT E

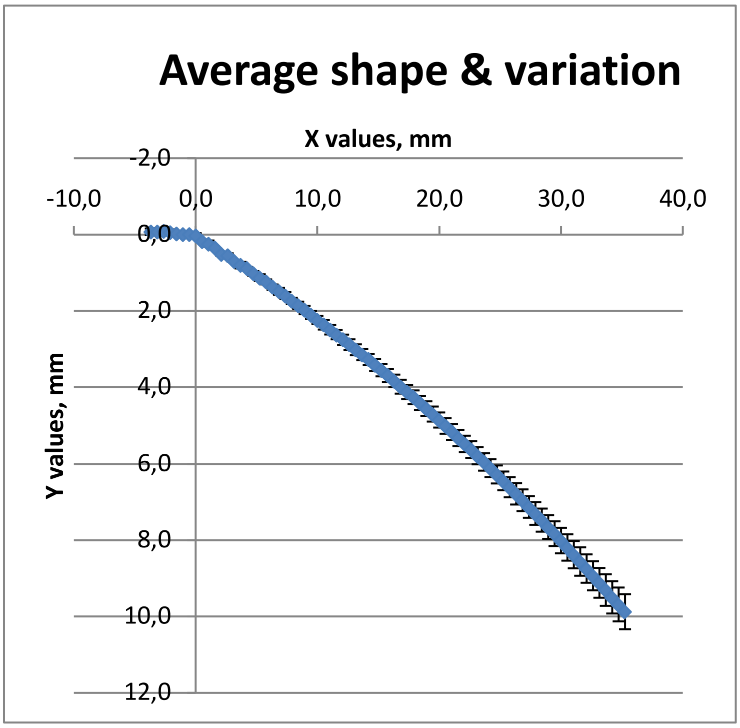
Average shape and variation with 3mm dispensing beak



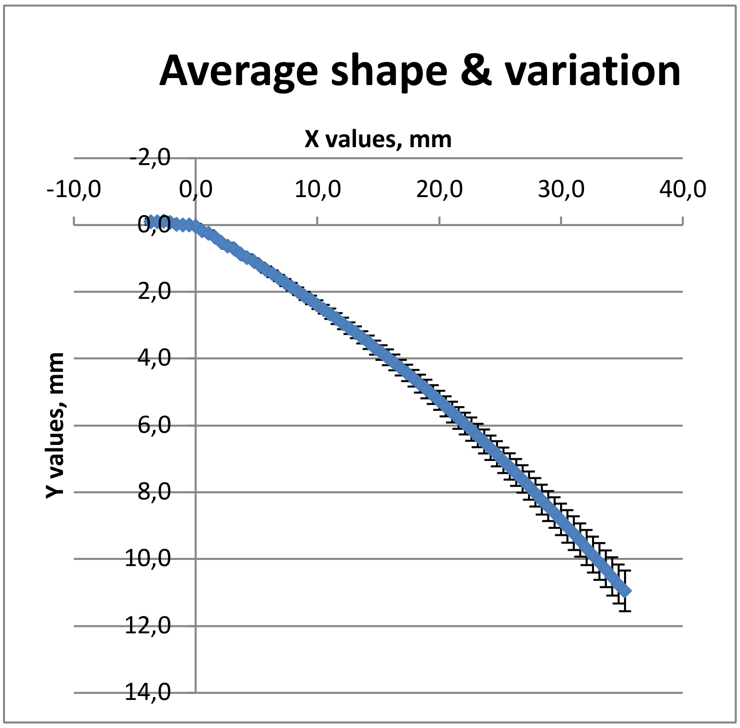
Graph 1: Test material A at dispensing speed 10m/min



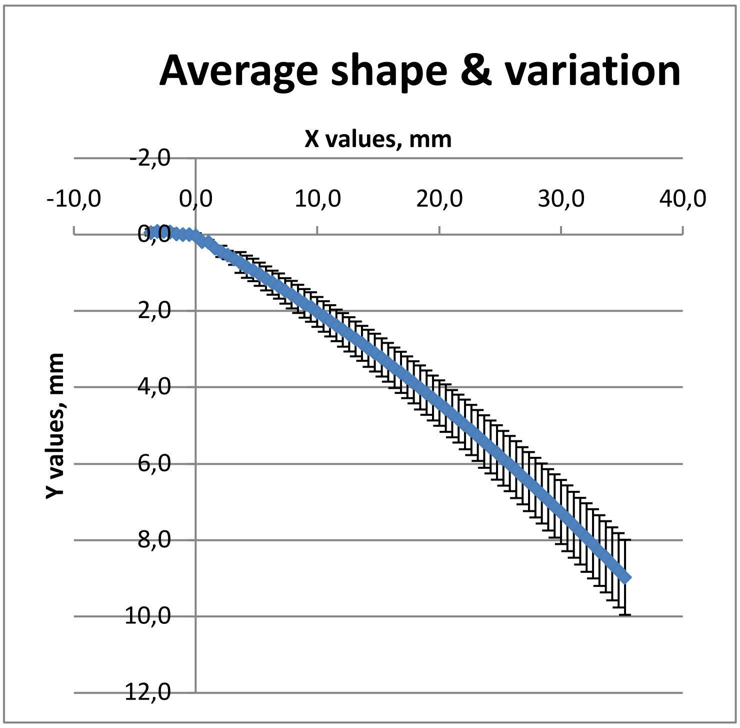
Graph 2: Test material B at dispensing speed 10m/min



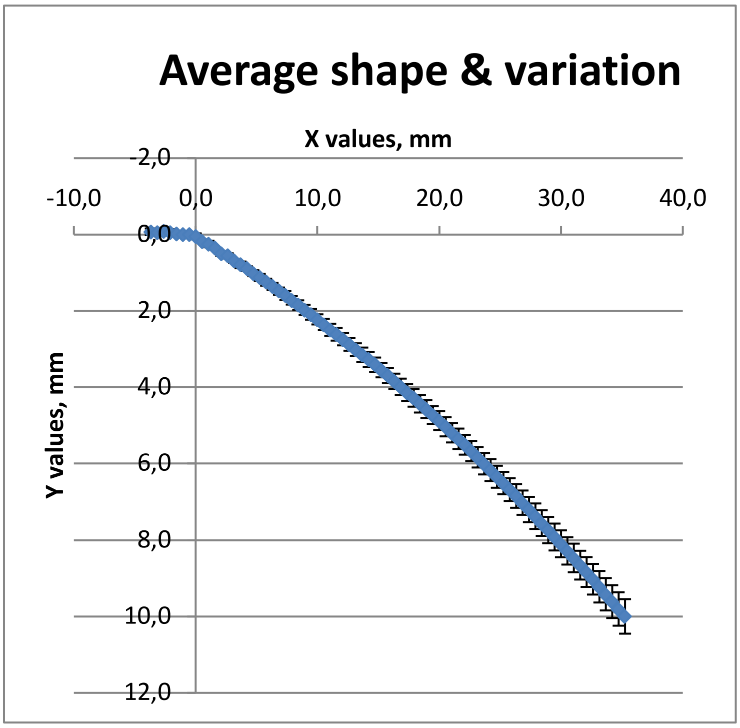
Graph 3: Test material C at dispensing speed 10m/min



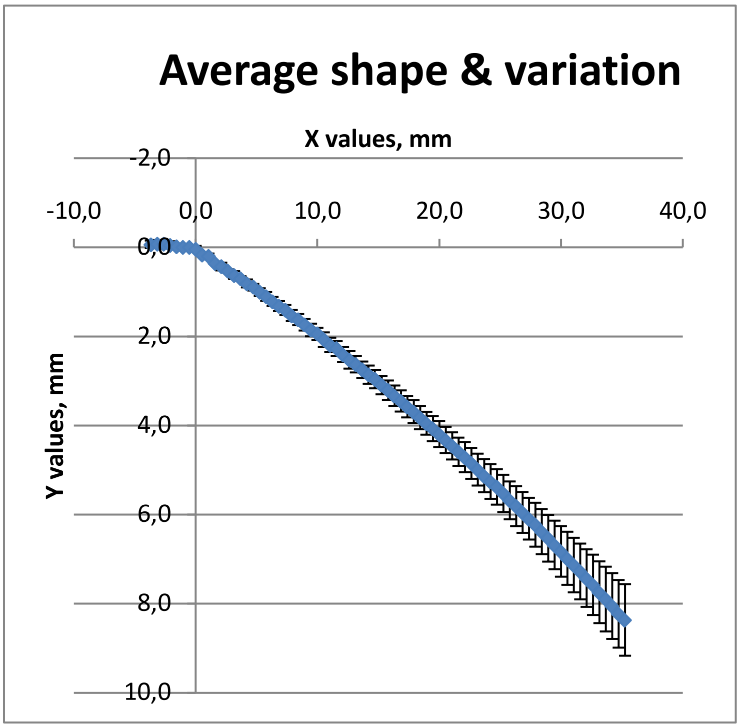
Graph 4: Test material D at dispensing speed 10m/min



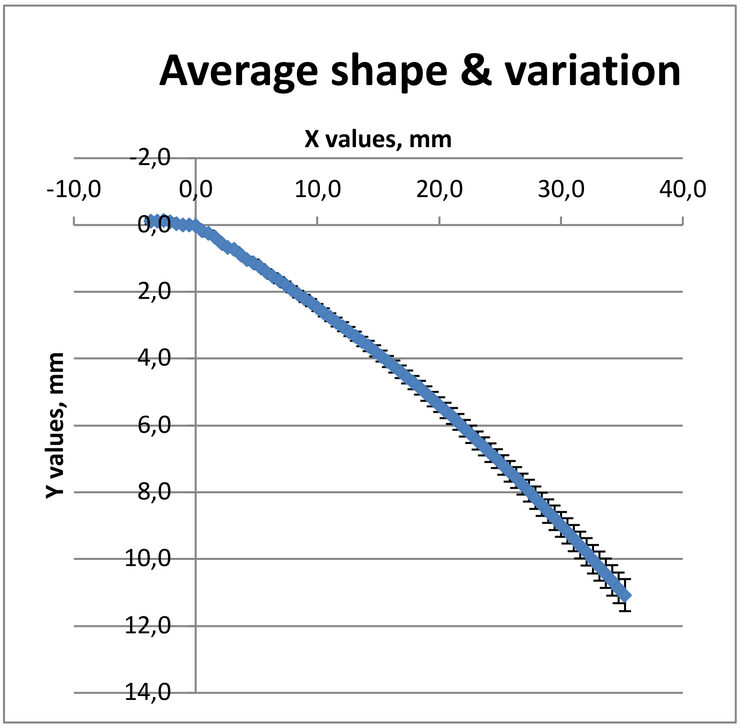
Graph 5: Test material E at dispensing speed 10m/min



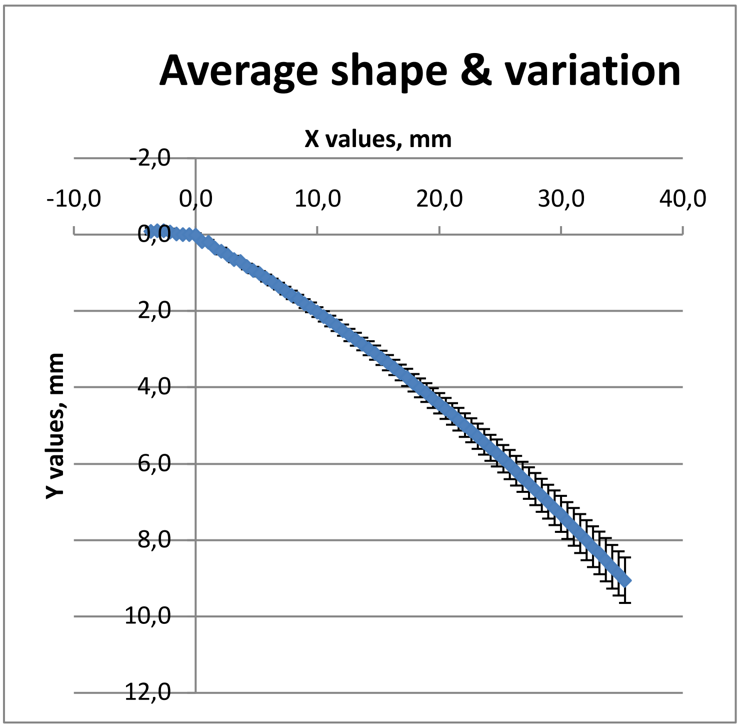
Graph 6: Test material F at dispensing speed 10m/min



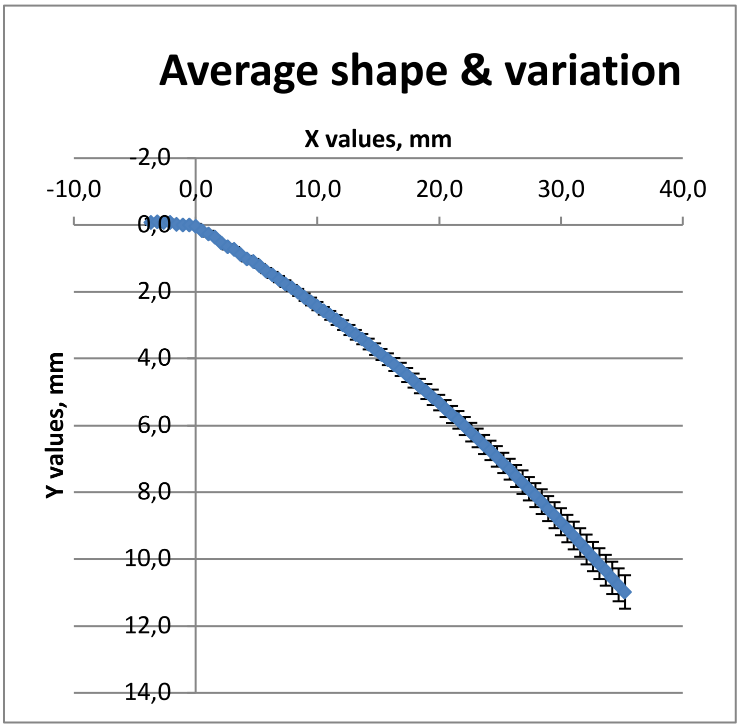
Graph 7: Test material G at dispensing speed 10m/min



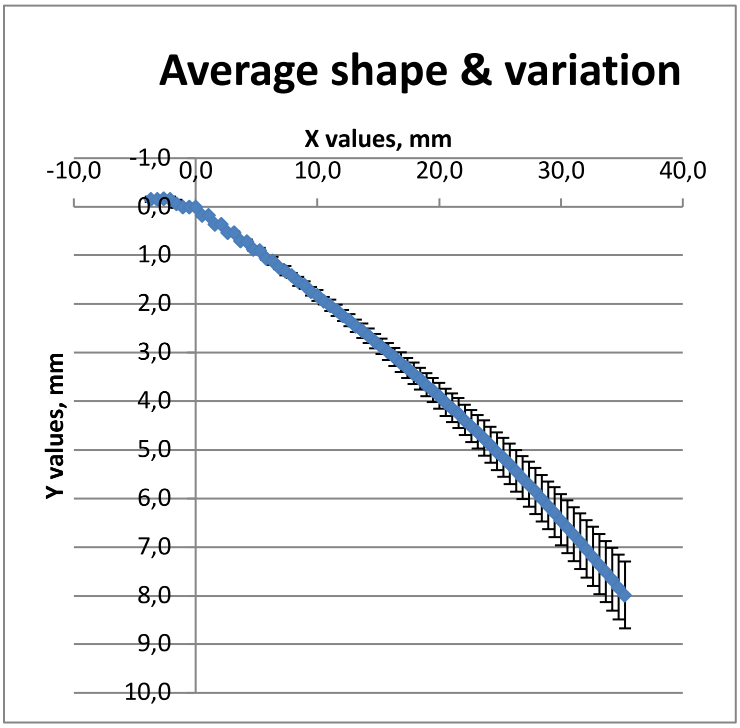
Graph 8: Test material H at dispensing speed 10m/min



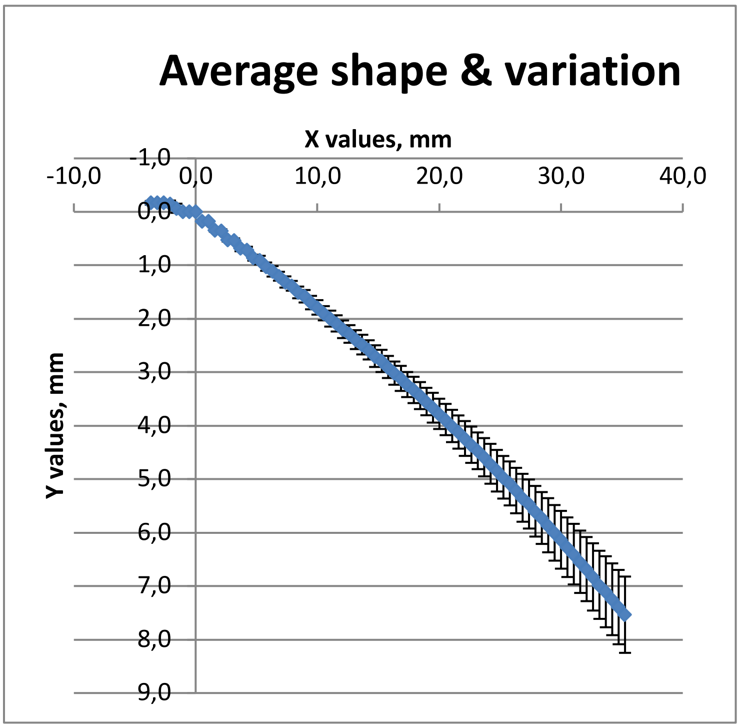
Graph 9: Test material I at dispensing speed 10m/min



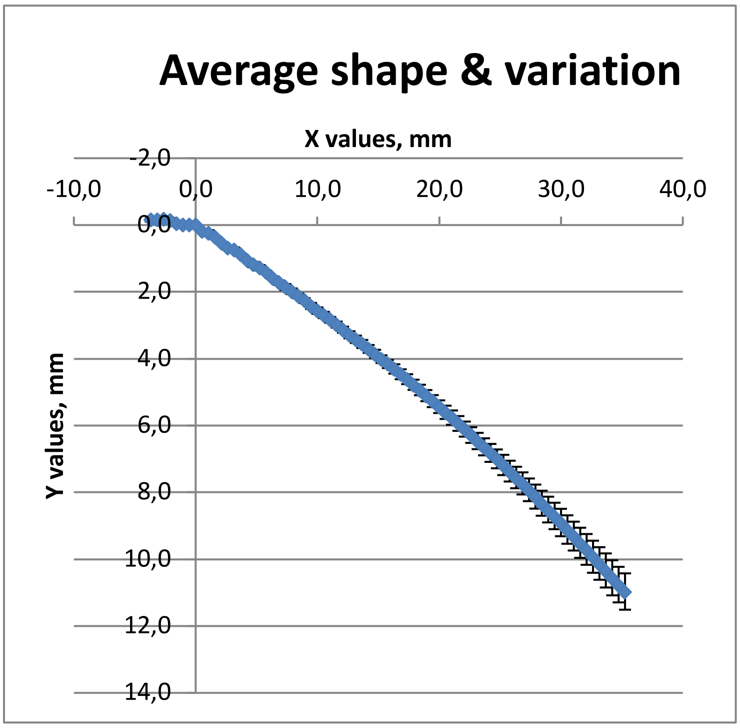
Graph 10: Test material J at dispensing speed 10m/min



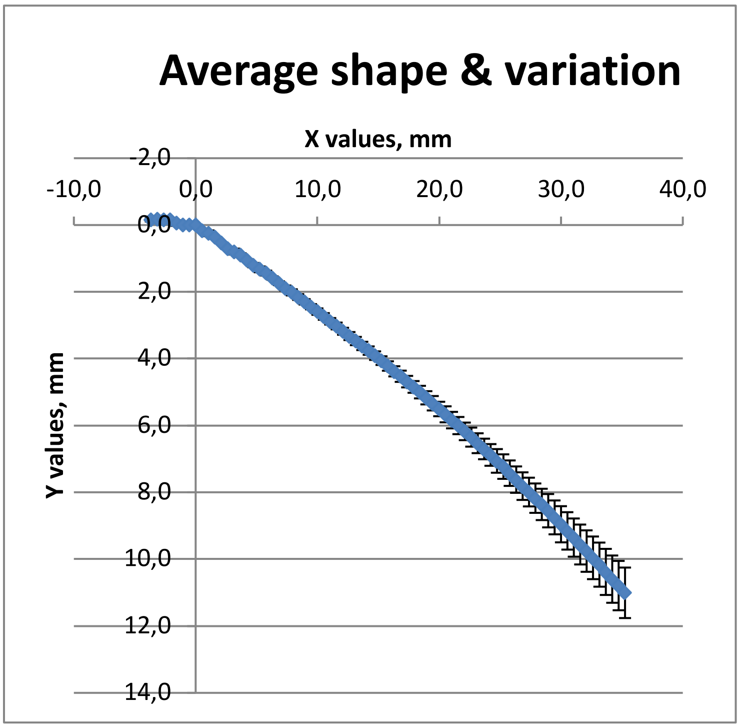
Graph 11: Test material A at dispensing speed 30m/min



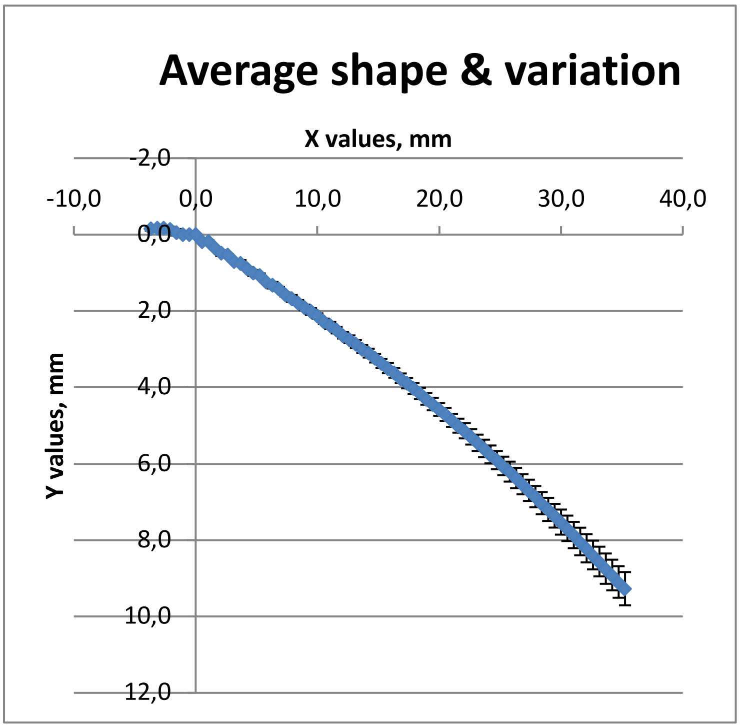
Graph 12: Test material B at dispensing speed 30m/min



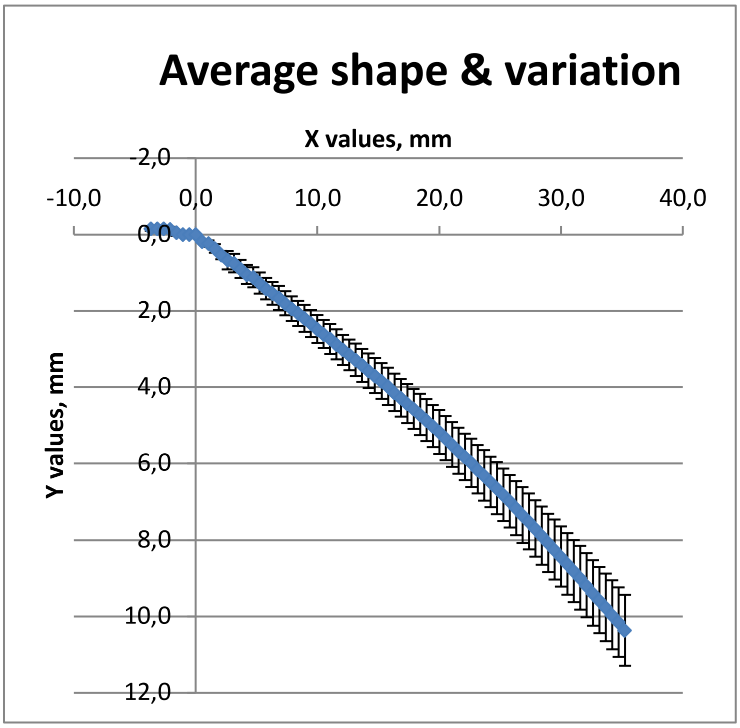
Graph 13: Test material C at dispensing speed 30m/min



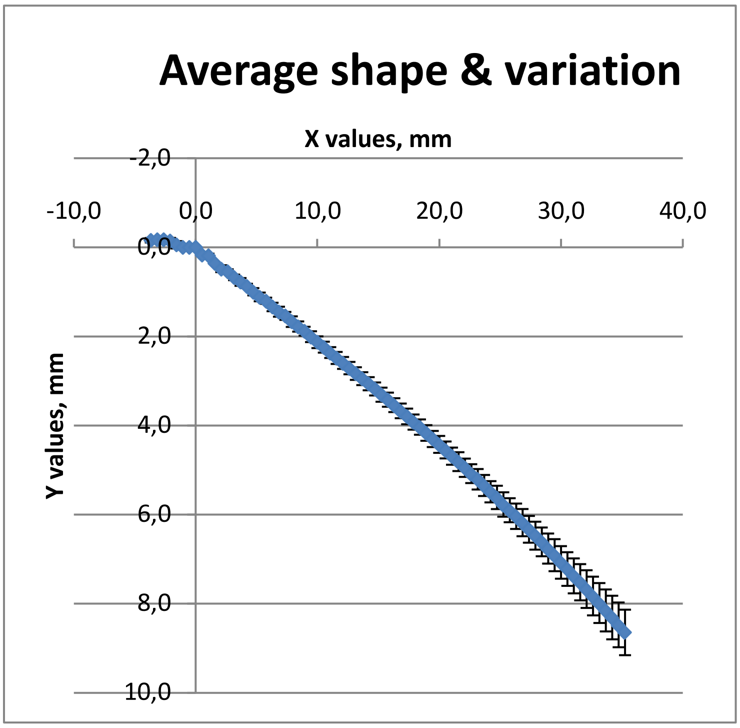
Graph 14: Test material D at dispensing speed 30m/min



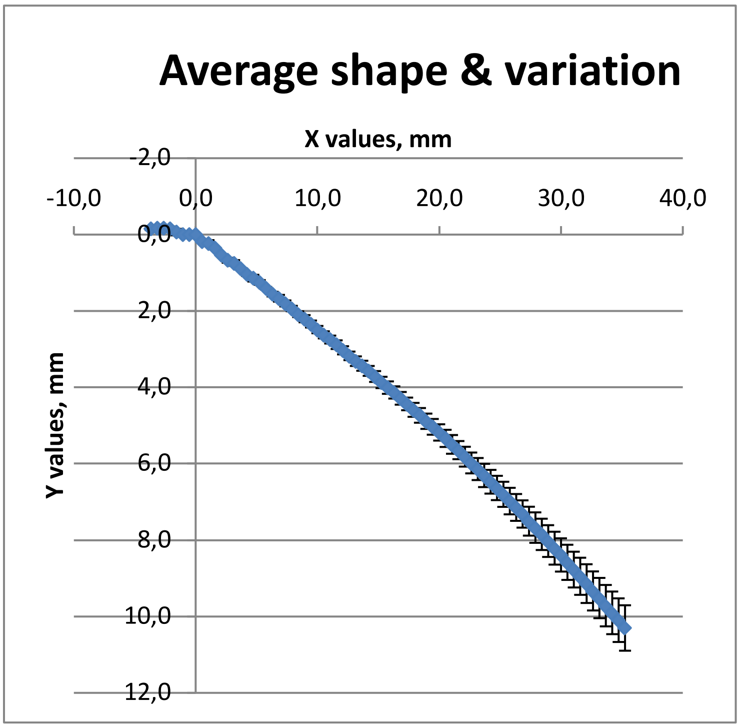
Graph 15: Test material E at dispensing speed 30m/min



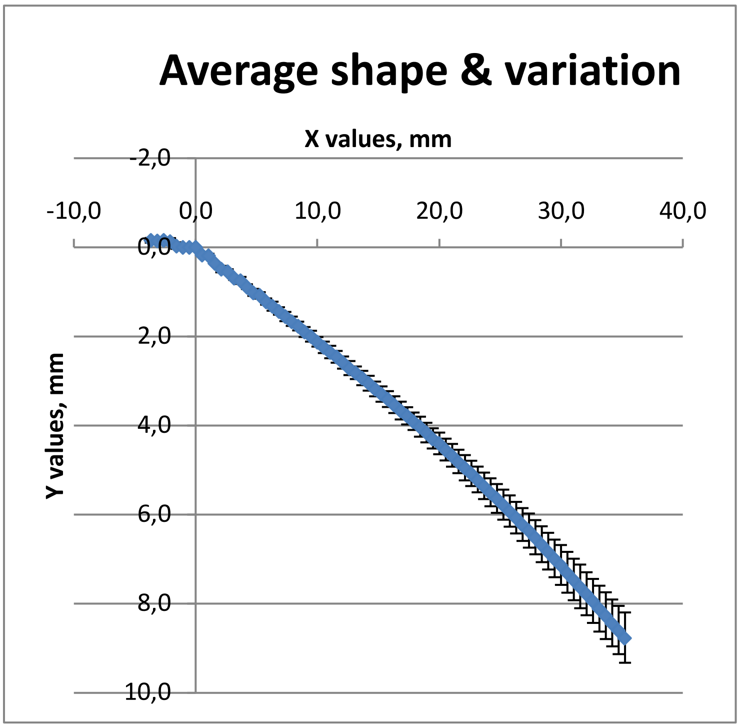
Graph 16: Test material F at dispensing speed 30m/min



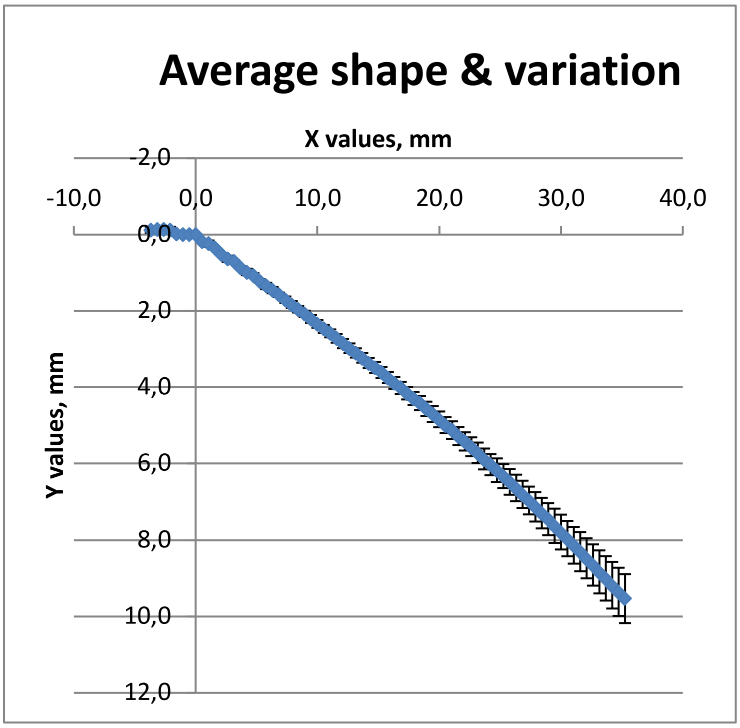
Graph 17: Test material G at dispensing speed 30m/min



Graph 18: Test material H at dispensing speed 30m/min



Graph 19: Test material I at dispensing speed 30m/min



Graph 20: Test material J at dispensing speed 30m/min