IMPROVING THE SEAM QUALITY IN BEVERAGE FILLED ALUMINIUM CANS TO ENSURE THE HERMETIC SEALING

Lappeenranta–Lahti University of Technology LUT

Master's Programme in Mechanical Engineering, Master's thesis

Master's programme in Industrial Design Engineering

2023

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ABSTRACT

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Master’s Thesis
2023
70 pages, 33 figures, 20 tables and 6 appendices
Examiners: Professor Juha Varis and Amir Togiani, D.Sc. (Tech)
Keywords: Beverage can, Leakage problem, Seaming parameters, Double seam, Nepal

This master’s thesis is a study on leakage problem from seaming area faced by beverage filled aluminium cans. Occurrence of leakage from a seam area means the hermetical sealing method of the can is compromised, resulting in release of gases and syrup along with the contamination of metal and microbes into the beverages inside the can. The thesis addresses the problem of can leakage problem in Nepal where the climate is moderate to hot, and the demand is quite high and increasing exponentially. This thesis aims to investigate the occurrence of leakages and find out the actual reasons for it. The research aims to provide necessary solution to the leakage problem by analysing the seaming parameters. The research scope is limited to the seam area of the can and does not include other problems related to filling, dent, corrosion, or gas dosing.

This thesis separately studies the seaming parameters of leakage and non-leakage cans. The seaming process is investigated in detail and each seaming parameters were analysed. The important factors related to seaming operation were acknowledged. The results were obtained from the experimentation and comparative analysis of both leakage and non-leakage cans. The accepted range of each seaming parameters for a proper seam formation and stoppage of leakage were proposed. The causes of leakages in most of the cases were linked to some inappropriate seaming parameters and reasons for seaming parameters being inappropriate or out of range, were further discussed. The solutions and necessary steps to solve those problems were suggested, which would correct the specified seaming parameters and eventually minimise the leakage problems.

SYMBOLS AND ABBREVIATIONS

Symbols

A	Internal Body Hook
B	Internal Seam Length
CD	Countersink Depth of the Lid
E	Expected Frequency
F	Observed Frequency
O	Actual Overlap
TH	Total height of an empty can
tb	Body Thickness
te	End Thickness
ts	Spring-Force Tolerance

Abbreviations

BH	Body Hook
BHB	Body Hook Butting
BP	Body Plate
CH	Cover Hook
CW	Chuck Wall
DF	Degree of Freedom
EP	End Plate
OR	Overlap Ratio
RPT	Ring Pull Tab
SC	Seaming Compound
SG	Seam Gap

SL	Seam Length
SOT	Stay on Tab
ST	Seam Thickness
SW	Seaming Wall
TR	Tightness rating

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1 Introduction

Can beverage industry has become quite competitive market in today’s generation. The initial manufacturing of a two-piece beverage cans (lid and can body) with drawing and ironing can be traced back to 1963 (Wędrychowicz, Kustra, Paćko, and Milenin 2021, p.1). Hundreds of billions beverage cans are manufactured worldwide each year, and the rate is increasing exponentially (Selles, Schmid, Sanchez-Caballero, Ramezani, and Perez-Bernabeu 2020, p.1). The can packaging offers longevity to the beverage product inside. Almost all the beverage products use some gases, mostly carbon dioxide, to increase the internal pressure and the shelf life of beverage. It is very important to have a hermetic seal so that the microorganisms will not be allowed to enter the beverage and the chance of food poisoning and other serious threats will be significantly diminished (AFDO 2011, p.3). The seaming technology to preserve and making airtight seal in beverage cans is remarkably useful for industrial production.

The design of the can body is an important factor for seaming. Mostly, aluminium metal is used to make the beverage can. During the starting phase, huge rolls of aluminium sheet (approximately 25,000 pounds and estimated to be 30,000 feet long) undergoes lubrication treatment method from both sides and transferred to cupping press. The sheet is cut into flat blanks, which are then drawn into hollow cups. Normally, the cupping press performs above 200 strokes per minute and 14 cut in 1 stroke. Those shallow cups are sent to body maker process where the punch supports the cups, and the metal is pushed consecutively through smaller circular ironing rings increasing the height and decreasing the can thickness and diameter. The speed of this process could be as much as 400 strokes per minute. During the final stroke of body maker process, the dome is shaped at the bottom of the can using a doming tool to provide strength, stability and assist in can packaging. The dome is the material bulged inwards the can and shaped like an arch bridge providing strength. The excess top part is trimmed to remove wavy and uneven edges and make a uniform can height. After the trimming process, can is sent to washer for removing lubricants and dried with hot air blower. (Romanko, Berry, and Fox 2004, p.1527.)

The critical process in making the aluminium can body is ironing combined with drawing and deep drawing. The punch in motion draws the cup into more than one ironing rings which consequently reduces the thickness of the can wall without changing any thickness of the can bottom. As the thickness of the can wall reduces significantly about 25-70 %, ironing process cannot be considered as a sheet metal forming operation. Frictional load between the cup and punch contacts within the deformation zone and helps in pulling the material of the cup through the punch. These frictional stress causes the deformation force to transmit by the punch, reducing the wall thickness and determining the final height of the can. It is assured that the materials are uniformly distributed throughout the can walls achieved from the ironing process. Also, desired mirror surface finishing is obtained by the can. (Schünemann, Ahmetoglu, and Altan 1996, p.1.)

After the trimming and cleaning process, unfinished can body goes to the labelling process. To decorate the can, wet ink is coated with clear varnish which secures the label and prevents scratches during transport and handling to some extent. Hot air blower is used to dry and cure the paint. Despite aluminium being a less reactive metal, organic coating is sprayed into inside of the can and transferred into the hot oven for curing purpose. This helps to prevent the slightly acidic beverage react with the aluminium and acquire the metallic taste. The next stage is the necking process. To reduce the diameter at the top and fit the size of the lid, necking is important. Coating must be done before necking process as the uncoated aluminium receives greater friction from the necking tools to the can walls (Turner 1998, p.21.) Necking is done in numerous stages with slightly different tools and die in each stage. The steps of necking process in an individual stage are clearly illustrated in Figure 1. The internal tool is inserted into the can and the can body is pushed through a series of progressive necking die that gradually decreases the neck diameter. Each stage is very difficult to recognize as the changes are so minute. These numerous stages of necking process done gradually helps to eradicate the formation of wrinkles in the can. After the necking process, the flange is created at the top of the can by bending and spreading out the top part which looks like a lip formation and allows the lid curl to be mounted on it.

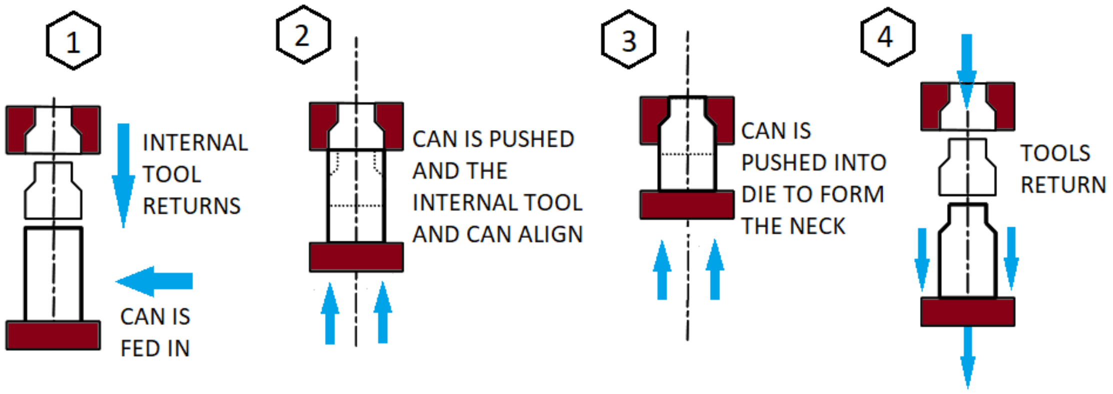
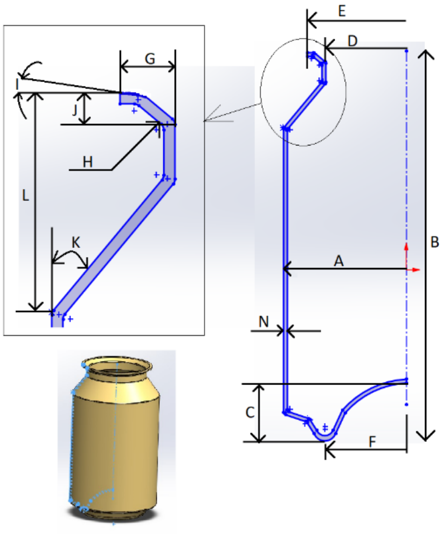


Figure 1. Steps of the necking process (Jordan & Miranda 2004, p.38).

The shape of the beverage can is carefully chosen combining the spherical and cuboidal shape. Sphere shape has the less contact surface area and no weak points. However, during packaging and stacking, it occupies larger area with void between the spherical containers. Cuboidal shape has great stacking capacity with almost no empty space between the cuboidal containers but has larger edges and weakest points. Thus, a cylindrical shape is chosen for the stability, strength and stackability of beverage cans. The column strength of an empty can should be about 250 pounds as the empty can experiences pressure during filling (Hosford & Duncan 1994, p.51). Can seal presses tightly against the top flange and pneumatic lift cylinder presses against the can bottom part. During this filling process, empty can must not buckle and able to withstand huge pressure. Also, during seaming and stacking, the can experiences huge pressure from top and bottom. So, the can walls should not be thin enough which does not meet such requirement. Figure 2 shows a drawing of an empty can where all the important dimensions are labelled. The finished cans are well inspected for any kind of defect, fractures, and pinholes. Dimensional checks and performance testing are done, and the parameters should be within the tolerances.



PARAMETERS
A- OUTSIDE BODY DIAMETER
B- FINISHED CAN HEIGHT
C- DOME DEPTH
D- NECK PLUG DIAMETER
E- FLANGE DIAMETER
F- STAND DIAMETER
G- FLANGE WIDTH
H- OVER FLANGE RADIUS
I- FLANGE ANGLE
J- SEAMING CLEARANCE
K- NECK ANGLE
L- NECK HEIGHT
N- BODY SIDE WALL

Figure 2. Detailed drawing of an empty can with all the parameters labelled.

Lids secure the opening of the can body and seals the beverage inside the can. The design of the lid is very important from the seaming perspective and a lid sample can be seen in figure 3. The outer curl at the top of the lid mounts around the flange of can body for seaming purpose. Manufacturing of the lids also starts with a huge coil of aluminium sheet. The aluminium alloy used in lids differs than that of can body as lids requires higher strength whereas the can body requires ductility for ironing. Blanks are cut from the aluminium coil, which is like the process of can making. The blank undergoes several shell forming processes. Basically, six types of dies and tools are used in shell forming process. They include draw die, upper piston, die centre, lower piston, die core ring and panel punch (Han, Yamazaki, Hasegawa, Itoh, and Nishiyama 2011, p.872). This shell forming process makes the countersink depth in lid for the chuck to grip the can during seaming. Also, panel depth and can opening are formed through punch. The scoring operation is conducted which helps to decrease the amount of force required to open the tab to an easy level (Page, Edwards, and May 2003, p.131). After the shell forming, the curling process takes place where the outer edge of the lid is curled with a deforming tool so that the curl design uniformly fits the can flange for seaming process. Seaming compound is then placed into the inside of the curl. The commonly used seaming compound in beverage lids is WBC 4721 (Henkel Corporation 2017, p.3). Seaming compounds helps to seal off the gap that may appear in double seam and create a hermetic seal. The amount of seaming compound placed in a lid should be carefully planned as it is a critical process. The last process in lid making is the tab attaching process which is joined through a rivet.

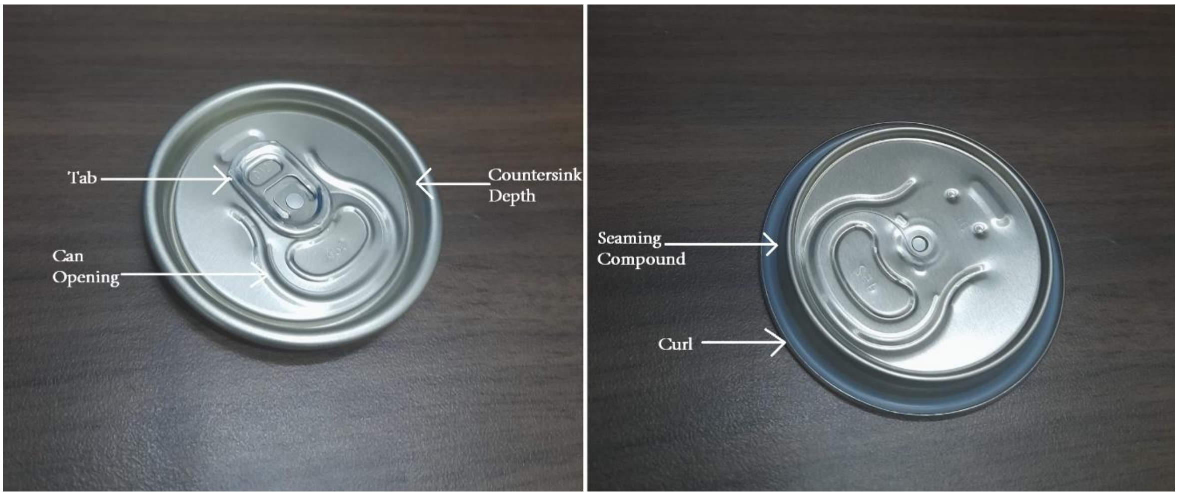


Figure 3. Sample of a lid from front (left) and back (right).

Based on tabs, there are two types of lids used in beverage industry. They are RPT (Ring Pull Tab) and SOT (Stay on Tab) lids. At first, there were no tabs and cans were used to open using a cutter. In 1960's RPT lids were developed as a user-friendly method of opening the can lids. RPT lids contain a ring as shown in Figure 4 where the ring is lifted to create a hole in the lid and pull up the tab to create the opening. RPT lids are advantageous for marketing scheme in beverage cans. Prize-full lids will be made, and the customer opens the tab, and the prize amount will be revealed underneath the opening tab. The problem with this type of lid was the tab containing sharp edges being tossed everywhere, polluting the environment and being a potential hazard to the plants and animals.

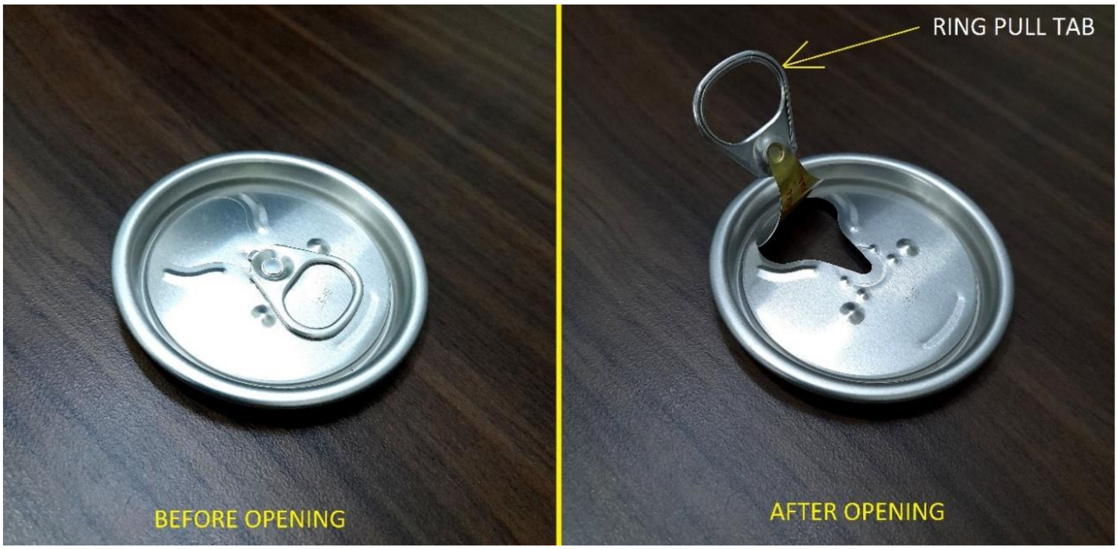


Figure 4. Opening method of a RPT Lid with before and after opening procedure.

Tackling this problem of littering, SOT lid was developed with a clever engineering. The opening process starts with lifting the tab end. At first, the tab works as a second-class lever. Lifting force is applied at the end of the tab, load is at the rivet and fulcrum is at the tip of the tab. As soon as the vent is opened, the tab works as a first-class lever. The load changes to the tip of the tab and rivet acts as a fulcrum. So, lifting the tab end presses the can opening downwards as shown in figure 5. This principle attaches the tab within the can and prevents the littering. As billions of cans are being manufactured and a reduction in a lid size could save lots of aluminium. With this idea of conservation and to make the can lightweight, the lid diameter has been reduced gradually over the years. The lid size which was 211 (68.3 mm in diameter) has now been reduced to 202 that is equivalent to 54 mm diameter (Yamazaki, Itoh, Watanabe, Han, & Nishiyama 2007, p.341).

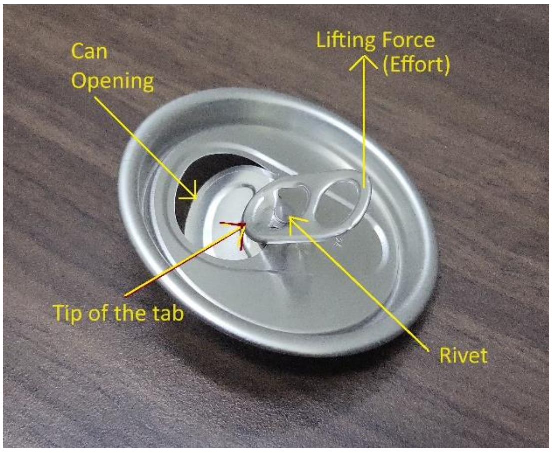
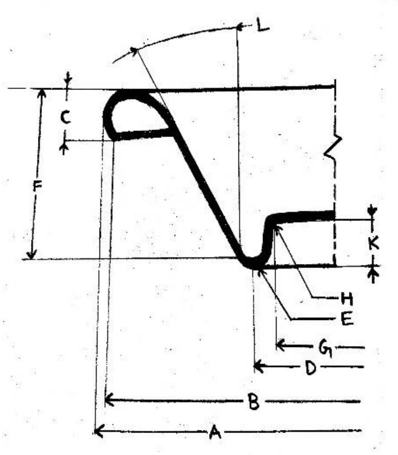


Figure 5. Opening mechanism of SOT Lid with clear illustration.

All the dimensions and parameters of the lid should be properly inspected. A detailed section-view of a 202 type SOT Lid is shown in Figure 6 labelling all the important parameters.



Parameters

A - Curl Diameter
B - Inner Curl Diameter
C - Curl Height
D - Countersink Diameter
E - Countersink Radius
F - Countersink Depth
G - Panel Diameter
H - Panel Radius
K - Panel Depth
L - Chuck Wall Angle

Figure 6. Detailed drawing of a 202 Dia SOT Lid.

The important parameters like countersink depth and chuck wall angle are very critical as it is directly involved with the seaming process. A slight difference in these critical parameters would lead to seaming chuck not being interference fit to the lid and result in improper seaming. Inner curl diameter is also critical parameter because the flange of the can needs to fit inside the curl of the lid. The curling of the lid should be done uniformly so that the seaming would be consistent on all sides. The lid should be chosen according to the design of the chuck.

1.1 Background

This study is based on academic research and analyzation on the seaming process in beverage cans and leakage problems associated with it. A specific beverage product company in Nepal, Agro Thai Foods Private Limited, was chosen for the research. This manufacturing plant deals with the production of beverage filled cans. Basically, two types of beverages are filled in this plant: Carbonated beverages and non-Carbonated beverages. In case of non-carbonated beverages, liquid nitrogen dosing is used. The plant includes the use of machineries like compressors, chillers, cooling towers, boiler, depalletizer, filler, seamer, warmer/cooler and shrink packaging. Among all of these, seamer is the major component of this plant. The seamer was installed in 2020 and has a capacity of seaming 120 cans per minute. It is a six-headed seamer which means that seaming operations are performed on 6 cans in 1 round.

In the previous year, a total of 35 breakdowns were occurred only in the seamer, excluding the stoppage that occurs less than ten minutes. The rate of production could be increased if the frequency of these long duration breakdowns could be reduced. The can rejection rate is around 2% – 2.5% for a nitrogen-dosed 250ml stubby can. The rejection could be analysed, and the root causes could be acquired. The minimisation of rejections could increase the product yield efficiency and have a huge impact on the company’s profit.

1.2 Research Problem

The demand of beverage products, especially can, is very high in south Asian regions as the temperature is moderate to hot, throughout the year. People are consuming a lot of energy drinks in Nepal, whether it is a carbonated or a non-carbonated product. The consumption volume of carbonated beverage is expected to reach 112 million Litres in Nepal by 2027 (Statista, 2023). The demand skyrockets during the summer season and it is very difficult to fulfil the market demand although the can line runs continuously 24 hours a day. The main problem is the leakage occurring in the cans which is found in a few hours or 1-2 days when kept in observation after tray packaging and holding the goods upside down. This problem will eventually damage the reputation of the company if the leaked products are found in the market. Furthermore, the rejection rate of cans increases.

Other problems include dents in the can body, bulging of cans, scratch or impressions in the can body, leakage found immediately after seaming and less pressured cans which are prone to damage. The problem of machine breakdowns, especially seamer, is also a huge problem which hampers the rate of production. The production stoppage time should be reduced to minimum by studying the possibility of required maintenance works. This thesis aims to analyse the problems and offer feasible solutions so that the company could benefit. Some of the questions that would be addressed in this research are:

- What types of data should be measured and gathered for the solution of leakage occurring in cans?
- What type of data analysis methods could be done to know the range of acceptable seaming parameters?
- What kind of changes can be done in the current seaming procedure/seamer design from the analysis of the data to stop leakages?

1.3 Research Objective

The main purpose of this research is to study the detailed seaming process and analyse the leakage occurring problems from seam area. A proper study will be done on the relation between the seaming parameters and occurring of leakages. This research will figure out all the possible causes of leakages in cans. The literature review will provide the information about the principles of double seam technology and the technical information related to it. All types of seaming parameters related to double seam technology will be studied. The favourable method of data collection will be chosen. There will be a study on the types of data that needs to be collected so that the link between the seaming parameters and the leakage from seaming area in cans, could be properly deduced. Various types of data analysis methods will be conducted to evaluate the relation between the deviation in seaming parameters and occurrence of leakage. At the end of this thesis, the most important and critical seaming parameters are to be known and the acceptable tolerance in which the leakage does not occur, are to be evaluated. It will guide the seamer operators and line engineers to perform the seaming setting in accordance with the result of the analysis. This thesis aims to enhance the performance of seaming procedure and thus help in the minimization of product rejection and boost company’s production.

1.4 Limitations

Running a beverage industry requires a smooth and controlled performance of machines. There are various challenges that can be faced in the beverage industry apart from leakages occurring in the cans. These are the other five problems that are directly faced by the cans:

- Filling valve filling inappropriately (low fill, high fill, empty fill, foaming issues)
- Infeed/Outfeed guides and worm-feed guides timing out, causing dents in the cans.
- Gear ratios out of sync causing damages and plant breakdown.
- Improper nitrogen dosing leading to bulging of cans or less pressured cans.
- Occurrence of corrosion in can body

Considering the scenario of problems faced, these types of problems are directly traced in the cans and are easily sorted out. Furthermore, after setting and ruling out the problems, most of these problems can be minimized to near zero. The problem of corrosion is also ruled out as the frequency of the occurrence of corrosion is quite low. This is because the products are highly demanded and consumed within a short period of time after production. The possibility of corrosion increases if the product is being stored for a long period of time. Unlikely, the problem of leakages is more of a concern as the frequency of leakage occurring from seaming area is quite high and it is difficult to trace directly. Some leakages are found directly after seaming, whereas others are found after few hours or few days. This makes the problem challenging where it stands out for addressing the problem before any other problems. There are also other various problems related to syrup formation and circulation, electrical and automation problems which will not be accounted for during this research. This thesis aims to find the right method to analyse and find the best possible solution to address the concerned problem regarding the leakage issues from seaming area of the can.

2 Research Methods

This section describes the methodology to obtain the required data or information and the approach that will be used in this research. The problem has been identified and a suitable approach to analyse the problem will be discussed after the literature review. The literature review will study the process and parameters of double seam technology which will give the right direction to this research methodology.

2.1 Literature Review

Double Seam is a recently developed technology to hermetically seal beverage cans and preserve the beverage inside the can for a long duration of time. The main principle of the double seam is to completely block the flow of any particles in both ways so that neither outside particles can get inside the can nor any inside particles can escape outside the can. The name ‘Double Seam’ refers to the two sets of seaming operations done on the can. It involves a first operation roller encountering the lid curl to pre-shape the curl into the can flange followed by second operation roller pressing the curl-flange combination into a hermetically sealed double seam. The machine that conducts double seam operation is called a seamer. A normal seamer can perform double seam operations at 50-100 cans per minute. In a modern high-speed seamer, the performance can exceed up to 2500 cans per minute in Ferrum F18 seamer.

To conduct a double seam operation, the basic equipment required are chuck, can, lid, first operation roller, second operation roller and lift cylinder. First, the chuck holds the lid onto the can body so that lid curl and can flange encounters each other. Then, the lift cylinder presses the can upwards from the bottom, stabilizing the can. As the can is held firmly by chuck and lift cylinder as seen in Figure 7, both the seaming rollers consecutively come into action and operate the double seaming process.

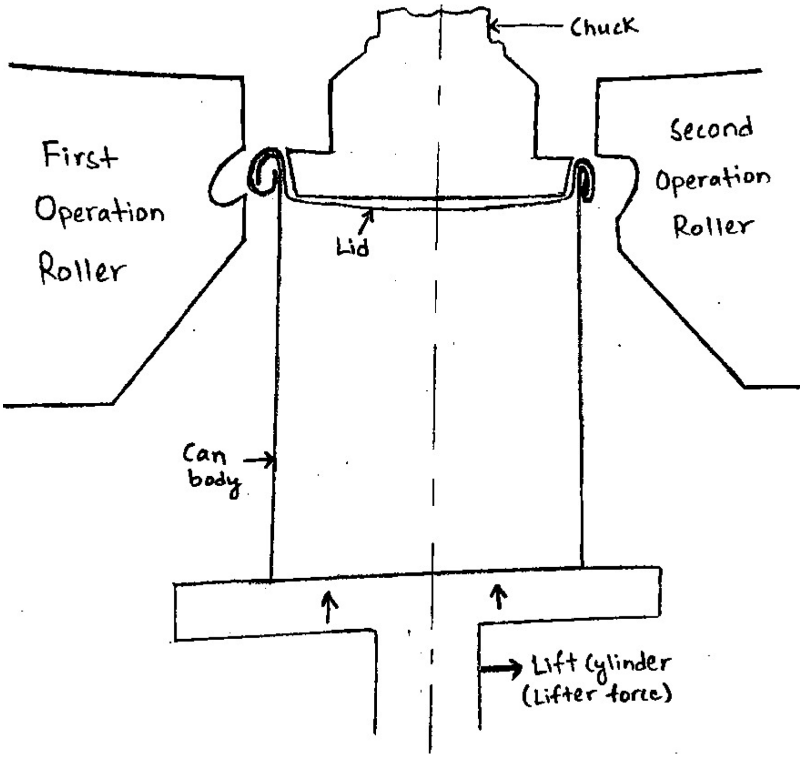


Figure 7. Double Seam formation in a beverage can (EHCAN, 2002).

The actual design of the seaming chuck can be seen at figure 8. The main part of the seaming chuck is the countersink area as labelled in the figure. The countersink area is slightly angled around 4 degrees to fit exactly in the lid countersink depth (Vågane, Birkeland, Wasbø, and Sivertsvik 2005, p.55). The topmost area of the countersink is the seaming area which encounters the lid and the groove of seaming rollers that pressed together in a circular motion forms a double seam. The threaded part of the chuck is inserted into the chuck shafts and the tools can be inserted into the holes seen in the chuck to tighten it. The chuck shafts are supported with gears and several bearings inside the seamer and attached with the main gear so the chucks will freely rotate continuously when the seamer rotates for the seaming operation. The seaming chuck must be inspected at a regular interval because there is a huge chance of material being wear out especially the seaming area of the chuck (BCME 2005, p.24). Even if there is a minute damage in the seaming area of chuck, it can hugely affect the hermetic sealing method of double seam and cause leakages.

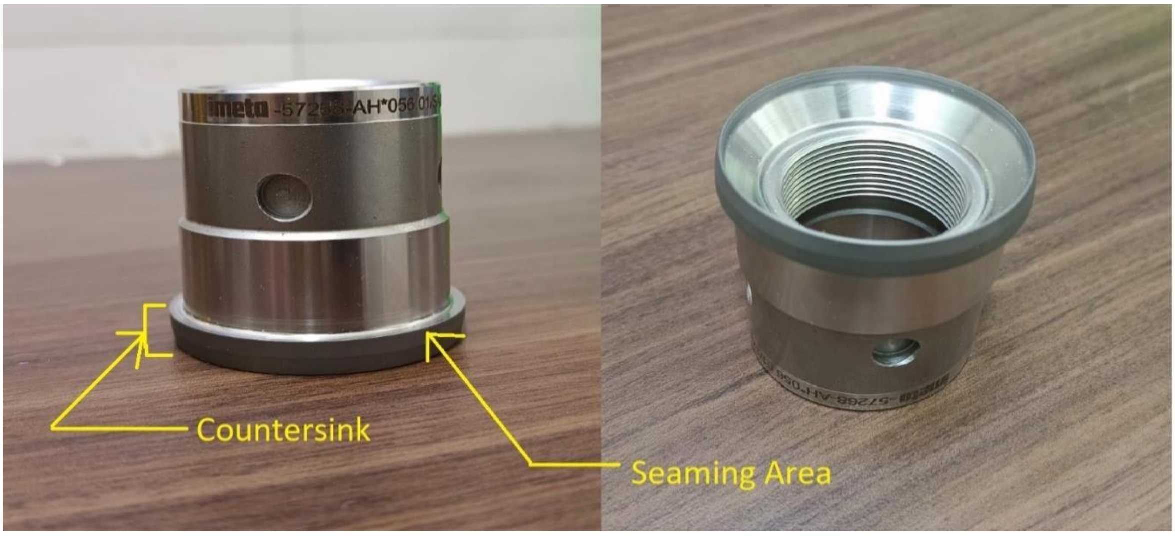


Figure 8. A closer look at the seaming chuck with countersink and seaming area defined.

Seaming rollers play the most crucial role in double seam. For a true double seam, two sets of rollers must perform a consecutive set of rolling operations against the chuck with initially the first operation roller and then followed by the second operation roller. It must be ensured that the seaming roller and chuck are not in contact during the whole operation. The seaming rollers must be freely moving without any axial play. Figure 9 shows an actual first operation roller and second operation roller manufactured by IMETA. Each seaming rollers consists of a durable bearing that supports the loads on the rollers during numerous seaming operations throughout the production. The threaded part of rollers gets fitted onto the holders which are then attached to the roller's shafts in the seamer. The rollers shafts are also supported by bearings but as the shafts doesn't rotate, there is not much load in the bearings. The shafts are supported by cam movement and tension springs are also attached. There are two specific marking stations in the seamer: one for first operation seaming and other for second operation seaming. At the first marking station, the cam mechanism allows the shafts of first operation rollers to release the tension in the spring and rollers comes nearer to the rotating chuck for first operation seaming. Similarly at the next marking station, the tension in the spring is released due to cam movement and second operation rollers comes nearer to the rotating chuck for final seaming.

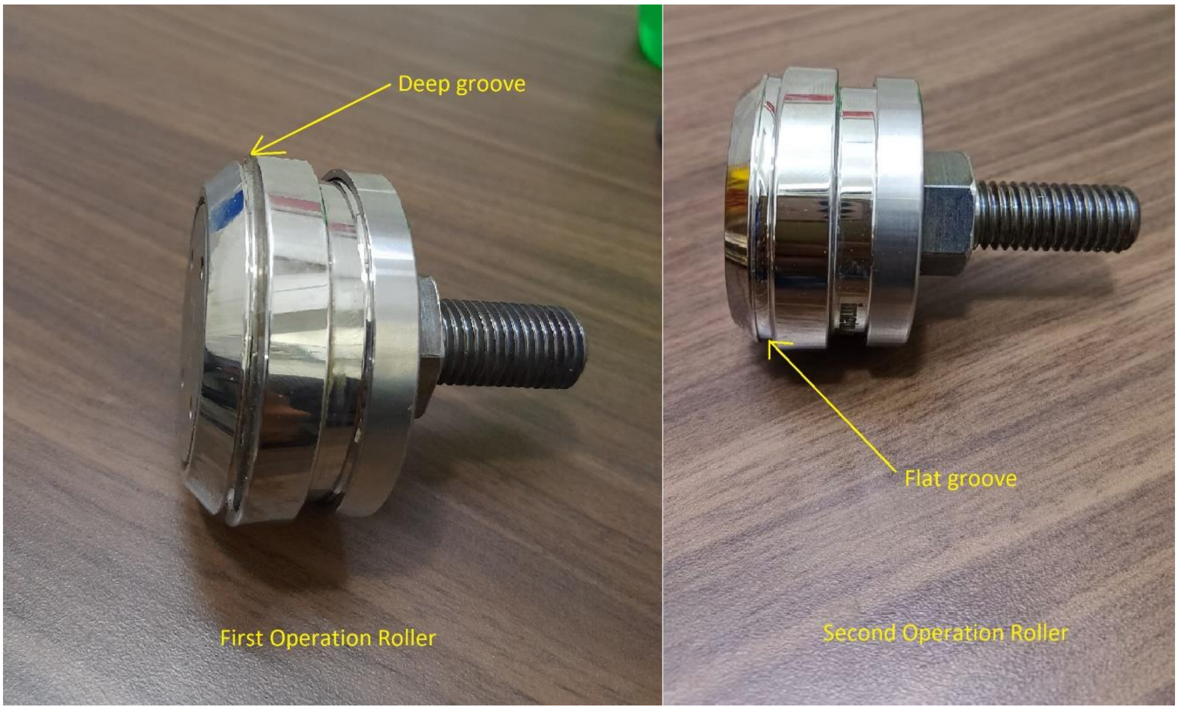


Figure 9. A closer look at the first and second operation seaming roller.

As shown in Figure 10, the seam formation can be seen after each seaming roller operation. Here, the grey portion represents the can flange and the non-shaded part represents the lid curl. The mechanism of the first operation roller is to increase the roundness of the lid curl and lay the curl inside of the can flange. The groove of the first operation roller is deep enough so that curling process takes smoothly and prevents flatness of the seam. This stage prepares the seam ready to be flat-pressed. The groove of the second operation roller is slanted and flat which makes the roller to flat press the seam and form a tightly squeezed double seam.

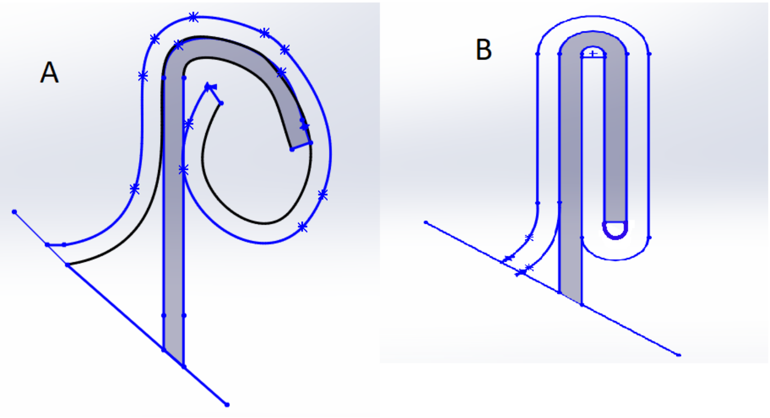


Figure 10. Seam formation by 1st (A) and 2nd operation roller (B) (Birkeland, Bergslien, Strand, & Sivertsvik 2005, p.280).

The nature of a good quality seam always consists of five layers of metal which are laid corresponding to each other and then pressed together without leaving any space between the layers as seen in Figure 11. The labelled diagram in Figure 11 is SW, Seaming Wall; CW, Chuck Wall; SC, Seaming Compound; BP, Body Plate (can) and EP, End Plate (lid).

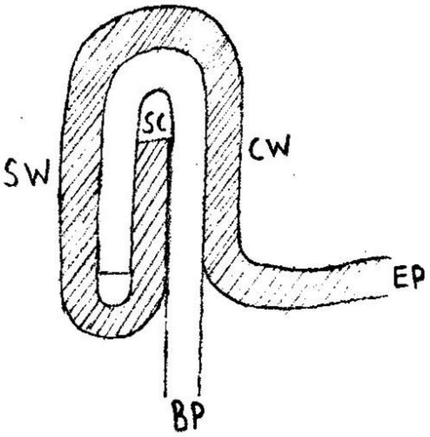


Figure 11. A good double seam formation (Vågane et al. 2005, p.54).

Out of five layers, three layers come from the lid curl which are labelled as shaded part and two layers from the can body flange. While metal being pressed against each other, there may be some imperfections which will be compensated by seaming compound that is already in the lid curl (Boda & Popa 2014, p.101). The seaming compound ensures that the void is filled, and the double seam is hermetically sealed.

2.1.1 Double Seam Parameters

There are several parameters that must be taken in consideration during the double seaming operation. Figure 12 shows all the important parameters of a double seam. The external parameters are SL (Seam Length) and ST (Seam Thickness). To measure the external parameters, no incisions on the can seaming surface are required. Seam length is the total length from the top of the seam to the bottom of the seam. Seam thickness represents the total width of the seam. In other words, seam thickness describes the compression of five layers of metal in a double seam.

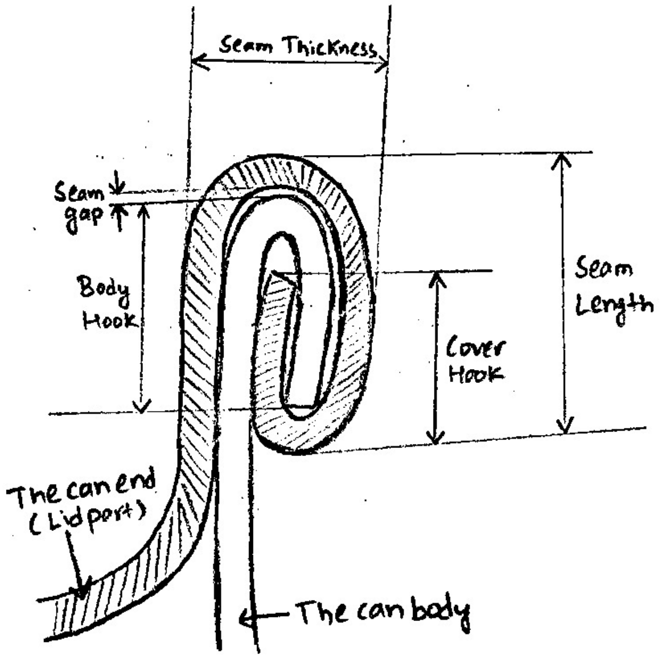


Figure 12. Parameters of a double seam clearly illustrated.

The internal parameters are Body Hook (BH), Cover Hook (CH), Seam Gap (SG) and Overlap. Body hook is the length of the can flange that is bent inwards the seam. Similarly, cover hook is the length of the lid curl that is bent inwards the seam. Overlap is the length between the end of the cover hook and the end of the body hook. Overlap is a critical factor and represents the interlocking portion between the flange and the curl. Seam gap is a formation of free space between the bottom of the lid curl and top of the can flange when they are superimposed on each other during seaming process.

Basically, there are three types of critical parameters that needs to be considered for a leakage proof seaming. They are Overlap Ratio (OR), Body Hook Butting (BHB) and Tightness Rating. The parameters vary with the dimensional guidelines for each type of can and lid. Overlap ratio determines the overlap between body hook and cover hook to assure the seaming compound is properly grasped under compression with standard seam thickness. Actual Overlap (O) and Internal Seam Length (B) can be clearly shown in Figure 13. Overlap Ratio of a double seam can be calculated as:

$$OR = {}^{O}\!/_{B} * 100\% \tag{1}$$

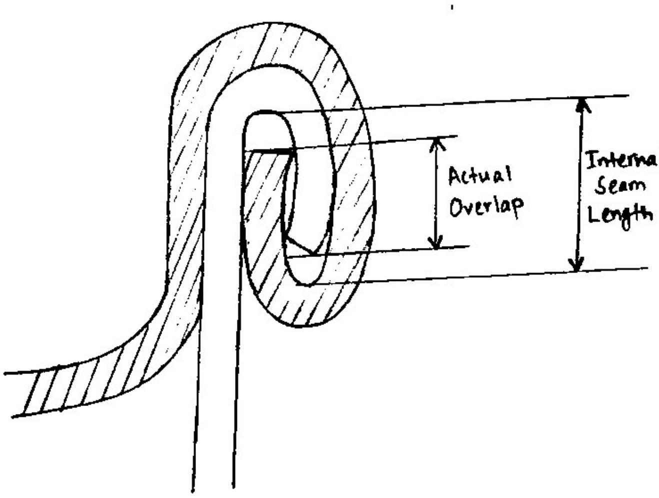


Figure 13. Overlap in a double seam.

Body Hook Butting (BHB) is another critical factor that needs to be calculated and assure that the parameter is within range of the double seaming guidelines. Body hook butting determines the percentage of internal seam length occupied by body hook or can flange. The quantity of empty space left behind by the body hook can be identified. Figure 14 shows the internal body hook (A) and internal seam length (B), which are required for the calculation of body hook butting. Generally, Body Hook Butting can be calculated as:

$$BHB = {}^{A}\!/_{B} * 100\% \qquad (2)$$

While using a manual method through seaming teardown, BHB can be measured as:

$$BHB = {}^{(BH - 1.1tb)}\!/_{[SL - 1.1(2te + tb)]} * 100\% \qquad (3)$$

where, BH = Body Hook, tb = body thickness, SL = Seam Length, te = end thickness

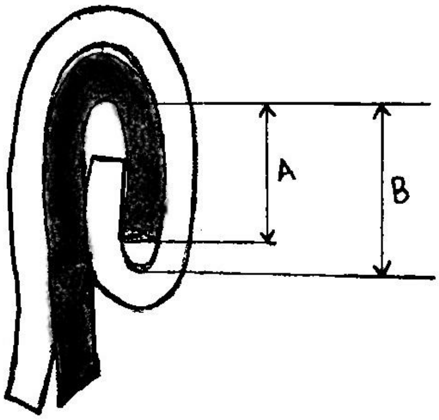


Figure 14. Body hook butting in a double seam.

Tightness Rating is one of the most critical factors in double seaming. Tightness rating is evaluated based on occurrence of wrinkles at the end of cover hook or lid curl. There is no measurement process to determine tightness rating and it can only be visually inspected by tearing out the lid curl from the seam. A proper seaming guideline requires the cover hook to be 100 % wrinkle free. Figure 15 clearly describes the different grade of wrinkles that can possibly occur at the cover hook.

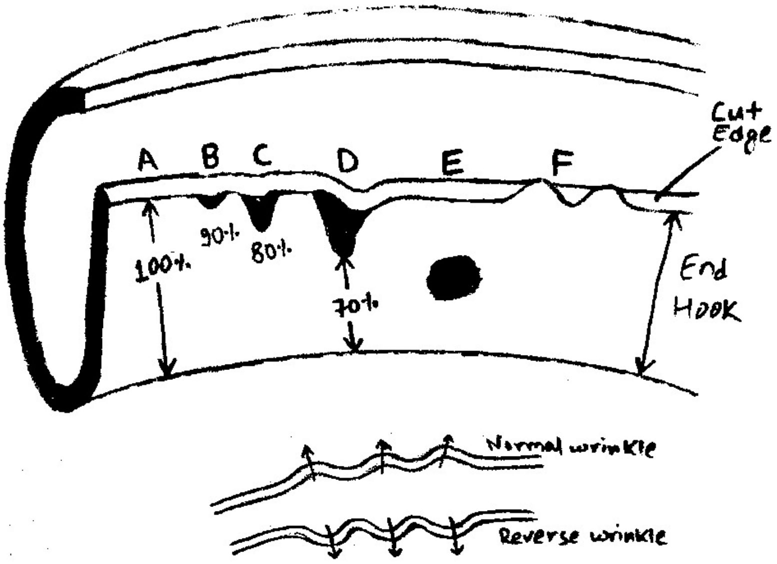


Figure 15. Tightness rating evaluation of a double seam (Moran 1999, p.165).

Grade A shows a perfect wrinkle free cover hook with even cut edge. Grade B – D shows occurrence of 90% - 70 % wrinkle on the edge of cover hook possibly due to uneven rolling pressure or loose roller setting. Grade E shows a dent occurring in the middle of cover hook with even cut edge due to seaming compound. Grade F shows the edge of cover hook over ironed which is possibly due to seaming too tight. Reverse wrinkles can also be seen in Figure 15. This type of wrinkles appears during first operation and does not go away even if the second operation is tight enough. Reverse wrinkle does not pose a great threat in causing leakage directly. However, if the material folds over itself and forms puckers, spurs or pleat, leakage may occur (Moran 1999, p 174).

2.2 Methodology

This research will be based on quantitative analysis. From the literature review, it is known that there is possibility of measurement of every critical parameter of a seamed cans. To study the causes of leakages and finding the similarities between every leaked can, this research will conduct experiments on the actual leaked cans and non-leaked cans also. The parameters that will be collected are seam length, seam thickness, body hook, cover hook, body hook butting, overlap percentage and tightness rating. The experiment will be conducted on 50 leaked cans and 50 non-leaked cans from 250ml nitrogen dosed juice filled stubby cans. The cans that are to be experimented will be taken from the cans that are kept in observation and hold upside down for a minimum of 24 hours to observe the leakage.

The sectioning method will be used to measure the seaming parameters on the cans. Sectioning method provides the accurate measurement as it is done through computer. Sectioning method involves two types of devices. One is cutter which is used to cut the cans using sawing blades that rotates at faster rpm. Figure 16 shows the view of seam cutter machine. The cans will be cut at two sections at diametrically opposite sides to check the uniformness of the seam.

Figure 16. Cutter device for sectioning of cans.

The view of the cross-section of the seam can be seen in Figure 17, after the cans are processed through cutter.

Figure 17. Cans after being sectioned from cutter.

The next machine is the seam view machine. After cutting the can, the cross section of the seam is put inside the magnifying chamber of seam view machine as shown in Figure 18. Before putting the can, the cross-section is well brushed for the better view of the seam profile. The seam profile of the checked cans is projected to the monitor as the data is transferred by the seam view machine to the computer through a software. The magnified seam profile is inspected, and the measurements of seam parameters are automatically calculated by the software.

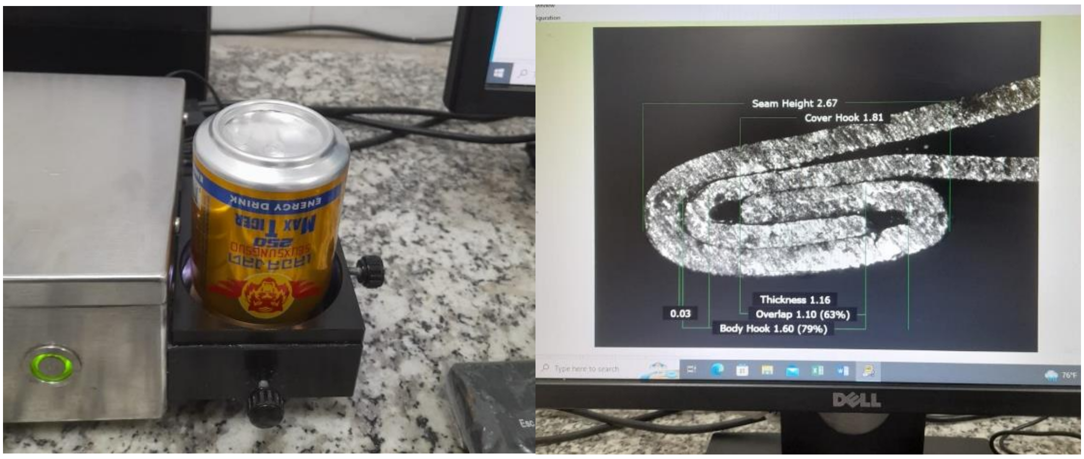


Figure 18. Sectioned can kept on magnifying chamber of seam view.

All the data can be collected by this sectioning method except the tightness rating. Tightness rating is rated visually by looking at the wrinkles formation on the cover hook. For this, the seaming area must be cut using a nose plier and cover hook should be manually stripped off as seen in Figure 19.

Figure 19. Manual teardown process of a can.

After collecting all the data, each data sets will be separately analysed and there will be comparisons between the leaked cans and non-leaked cans. There will be bar-diagram representation for the frequencies for each group. Data will be tested for probability distributions and normal distributions. Also, there will be tests to find better probability distribution curves. Correlation analysis will be conducted to find the similarities between data. Regression analysis will also be done to know the future trends and patterns. Lastly, curve fittings and error analysis will also be conducted. Overall, the critical seaming parameters along with their tolerance level will be generated at which the leakage does not occur. There will be further analyzation on the data sets on what types of factors affect the data sets. The discussions will be done if the data sets are too much deviated and how it can be controlled.

3 Results

The results were obtained through the seam view method by making two diametrically opposite cuts at the can seaming area and observing the section view. 50 leakage cans were taken for the experiment as well as 50 non-leakage cans. To choose the cans for experimentation, cans were packed into a paper cartoon tray, shrunk with plastic film, and held upside down for a minimum of 24 hours. After 24 hours, the cans containing leakage were observed and 50 leakage cans were taken out for experimentation. To take out the non-leakage cans, the cans were further held upside down for a week and observed for looseness or any beverage leakages from seaming area. From those cans, 50 non-leakage cans were selected, that were ensured with full nitrogen pressured without any gas leakages and taken out for experimentation. Each can was cut at two sections, which were diametrically opposite and therefore 100 data were collected for each leakage and non-leakage group. Table 1 and 2 shows the seaming parameters calculated from leakage cans and non-leakage cans respectively. The full test report of seaming parameters obtained from seam view machine is shown in Appendix 1 to 6.

Table 1. Seaming Parameters of 50 Leakage cans.

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
1	1.21	2.66	0	1.51	1.97	1.13	66	98	100
2	1.17	2.7	0.01	1.55	2.04	1.18	67	98	100
3	1.19	2.67	0.03	1.77	1.53	0.98	59	74	90
4	1.17	2.7	0.03	1.75	1.76	1.16	66	86	90
5	1.16	2.7	0.01	1.8	1.56	0.97	54	73	100
6	1.15	2.7	0	1.77	1.7	1.09	63	84	100
7	1.15	2.8	0.01	1.46	2	0.94	49	92	100

Table 1 continues. Seaming Parameters of 50 Leakage cans.

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
8	1.2	2.77	0	1.41	1.94	0.89	50	92	100
9	1.17	2.69	0.02	1.84	1.73	1.21	68	82	100
10	1.19	2.69	0	1.73	1.47	0.84	48	70	100
11	1.18	2.69	0.02	1.8	1.81	1.21	69	87	100
12	1.19	2.71	0.03	1.78	1.51	0.93	57	76	100
13	1.21	2.7	0	1.63	1.97	1.22	67	96	80
14	1.19	2.67	0	1.53	2.02	1.11	62	96	80
15	1.16	2.64	0.03	1.75	1.71	1.14	68	83	100
16	1.18	2.68	0.03	1.87	1.48	0.98	56	70	100
17	1.25	2.77	0.01	1.56	2.13	1.19	62	99	70
18	1.29	2.72	0.01	1.45	2.11	1.11	59	99	70
19	1.16	2.64	0.01	1.72	1.68	1.09	62	82	90
20	1.18	2.63	0.03	1.73	1.58	1.01	57	76	90
21	1.2	2.66	0.01	1.8	1.63	1.07	61	78	100
22	1.19	2.69	0.08	1.9	1.56	1.13	64	74	100
23	1.17	2.68	0.03	1.72	1.58	0.97	56	77	100
24	1.16	2.71	0	1.82	1.77	1.16	64	84	100
25	1.19	2.7	0.04	1.75	1.62	1.02	59	78	100
26	1.21	2.7	0.11	1.74	1.63	1.08	65	79	100
27	1.23	2.65	0.03	1.63	1.96	1.26	71	98	100

Table 1 continues. Seaming Parameters of 50 Leakage cans.

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
28	1.25	2.69	0.01	1.56	1.83	1	56	88	100
29	1.19	2.68	0.03	1.82	1.69	1.15	65	82	100
30	1.19	2.64	0.01	1.76	1.56	1	59	75	100
31	1.19	2.69	0.04	1.77	1.79	1.19	71	88	100
32	1.19	2.73	0.01	1.76	1.52	0.86	48	69	100
33	1.16	2.72	0.03	1.61	1.84	1.07	65	89	100
34	1.2	2.68	0.01	1.74	1.98	1.36	78	97	100
35	1.19	2.66	0.02	1.8	1.61	1.04	59	76	100
36	1.19	2.73	0	1.75	1.79	1.12	63	85	90
37	1.19	2.69	0.12	1.79	1.62	1.15	68	80	90
38	1.19	2.72	0.04	1.77	1.84	1.22	69	88	100
39	1.3	2.71	0.02	1.68	1.74	1	57	87	100
40	1.28	2.7	0.01	1.89	1.8	1.27	74	90	90
41	1.2	2.73	0.03	1.9	1.56	1.05	58	72	90
42	1.2	2.71	0.04	1.76	1.63	1.01	56	77	100
43	1.27	2.54	0.01	1.86	1.73	1.31	77	87	100
44	1.33	2.65	0	1.86	1.67	1.14	66	82	100
45	1.18	2.68	0.06	1.8	1.45	0.96	55	70	100
46	1.2	2.69	0.02	1.81	1.71	1.14	65	81	100
47	1.2	2.68	0.04	1.46	2	1.1	61	99	90

Table 1 continues. Seaming Parameters of 50 Leakage cans.

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
48	1.22	2.68	0.02	1.56	1.8	0.99	57	88	90
49	1.21	2.8	0.03	1.49	2.01	1.02	55	94	100
50	1.24	2.81	0.06	1.35	1.82	0.7	38	84	100
51	1.19	2.68	0	1.83	1.73	1.22	73	85	100
52	1.19	2.65	0.03	1.75	1.53	0.94	53	71	100
53	1.19	2.74	0.04	1.75	1.7	1.03	58	82	100
54	1.19	2.65	0.01	1.82	1.68	1.16	68	83	100
55	1.18	2.77	0.03	1.78	1.52	0.84	47	67	100
56	1.17	2.7	0.03	1.76	1.63	1.01	56	77	100
57	1.18	2.77	0.03	1.52	1.8	0.89	49	84	90
58	1.24	2.82	0.01	1.32	1.95	0.76	40	89	90
59	1.17	2.71	0.07	1.79	1.59	1.02	57	76	100
60	1.21	2.68	0.01	1.79	1.7	1.12	65	81	100
61	1.21	2.71	0.02	1.79	1.67	1.09	62	80	100
62	1.2	2.7	0.02	1.79	1.61	1.01	56	75	100
63	1.15	2.66	0.1	1.69	1.66	1.01	56	81	100
64	1.18	2.65	0.02	1.77	1.76	1.18	69	86	100
65	1.19	2.58	0.02	1.79	1.65	1.14	67	81	100
66	1.19	2.68	0	1.76	1.56	0.96	54	74	100
67	1.15	2.66	0.04	1.77	1.6	1.03	58	76	100

Table 1 continues. Seaming Parameters of 50 Leakage cans

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
68	1.18	2.69	0.02	1.84	1.85	1.31	77	89	100
69	1.22	2.79	0.09	1.4	1.86	0.91	52	91	90
70	1.17	2.75	0.12	1.5	1.8	0.98	57	89	90
71	1.16	2.72	0.05	1.79	1.69	1.1	63	81	100
72	1.2	2.73	0.03	1.78	1.61	0.98	57	78	100
73	1.17	2.62	0.02	1.79	1.78	1.26	72	88	100
74	1.19	2.62	0.01	1.7	1.66	1.02	60	82	100
75	1.18	2.71	0.04	1.83	1.76	1.2	67	83	100
76	1.2	2.7	0.02	1.75	1.87	1.22	68	89	100
77	1.17	2.73	0.02	1.76	1.88	1.24	68	89	100
78	1.22	2.69	0.03	1.77	1.77	1.16	67	84	100
79	1.18	2.81	0.02	1.45	1.9	0.88	49	89	80
80	1.25	2.77	0.14	1.5	1.74	0.91	53	86	80
81	1.31	2.7	0	1.56	2.02	1.18	65	98	70
82	1.29	2.63	0.02	1.52	1.97	1.16	66	98	70
83	1.17	2.66	0.02	1.79	1.62	1.05	61	79	100
84	1.14	2.65	0.07	1.8	1.58	1.1	66	77	100
85	1.24	2.78	0.03	1.6	1.99	1.13	62	95	80
86	1.28	2.74	0.03	1.5	2.03	1.1	59	96	80
87	1.17	2.7	0.08	1.8	1.66	1.14	66	80	100

Table 1 continues. Seaming Parameters of 50 Leakage cans

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
88	1.19	2.73	0.05	1.79	1.78	1.19	69	88	100
89	1.19	2.67	0.06	1.73	1.84	1.23	71	89	100
90	1.16	2.71	0.02	1.8	1.71	1.12	64	81	100
91	1.19	2.74	0.05	1.82	1.72	1.14	65	83	100
92	1.13	2.68	0.1	1.74	1.71	1.14	69	86	100
93	1.35	2.79	0.09	1.44	1.96	1.01	57	93	80
94	1.3	2.67	0.01	1.49	2	1.1	61	97	80
95	1.17	2.75	0.03	1.81	1.51	0.91	51	69	100
96	1.19	2.72	0.05	1.76	1.44	0.8	45	67	100
97	1.17	2.65	0	1.66	1.95	1.28	71	97	90
98	1.27	2.67	0.02	1.5	1.98	1.11	64	98	90
99	1.26	2.69	0.04	1.54	1.98	1.14	63	95	70
100	1.25	2.65	0.03	1.51	1.99	1.16	66	98	70

Table 2. Seaming Parameters of 50 Non-Leakage Cans.

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
1	1.18	2.66	0.01	1.75	1.79	1.2	70	86	100
2	1.19	2.67	0.03	1.76	1.79	1.22	73	87	100
3	1.17	2.62	0.02	1.85	1.75	1.27	76	89	100
4	1.22	2.65	0.04	1.73	1.75	1.16	76	92	100

Table 2 continues. Seaming Parameters of 50 Non-Leakage Cans.

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
5	1.19	2.75	0.01	1.78	1.84	1.15	63	86	100
6	1.19	2.77	0.02	1.85	1.78	1.17	65	83	100
7	1.18	2.74	0.02	1.65	2.06	1.27	67	98	100
8	1.18	2.78	0.02	1.73	1.84	1.1	62	85	100
9	1.22	2.78	0.05	1.62	1.94	1.06	56	88	90
10	1.2	2.75	0	1.58	1.96	1.1	59	92	90
11	1.17	2.68	0.01	1.48	1.64	0.78	46	82	100
12	1.16	2.68	0.02	1.33	1.68	0.62	35	78	100
13	1.22	2.58	0.07	1.51	1.76	1.05	67	93	100
14	1.2	2.61	0.11	1.63	1.75	1.21	77	94	100
15	1.22	2.68	0.03	1.36	1.95	0.95	53	95	100
16	1.21	2.72	0.02	1.57	2.05	1.19	63	96	100
17	1.24	2.59	0.01	1.66	1.54	0.92	54	75	90
18	1.25	2.57	0.14	1.68	1.61	1.14	72	87	90
19	1.18	2.69	0.01	1.77	1.79	1.19	67	85	100
20	1.18	2.63	0.02	1.74	1.57	1	57	75	100
21	1.16	2.65	0.01	1.57	1.8	1.04	59	88	100
22	1.17	2.7	0.04	1.69	1.68	1	57	80	100
23	1.21	2.61	0.04	1.82	1.58	1.12	67	79	100
24	1.19	2.61	0.06	1.81	1.61	1.15	67	82	100

Table 2 continues. Seaming Parameters of 50 Non-Leakage Cans.

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
25	1.2	2.71	0.01	1.78	1.89	1.32	80	94	100
26	1.16	2.65	0.02	1.64	1.83	1.17	67	91	100
27	1.2	2.82	0.08	1.82	1.74	1.14	64	83	100
28	1.19	2.78	0.08	1.73	1.62	0.94	54	77	100
29	1.17	2.78	0.09	1.73	1.77	1.11	66	90	100
30	1.2	2.81	0.07	1.89	1.82	1.27	72	87	100
31	1.15	2.51	0.07	1.71	1.62	1.23	85	92	100
32	1.17	2.57	0.02	1.75	1.52	1.05	70	83	100
33	1.15	2.6	0	1.66	1.59	0.96	58	81	100
34	1.21	2.59	0	1.8	1.65	1.15	71	85	100
35	1.21	2.57	0.02	1.57	1.8	1.14	69	96	100
36	1.19	2.59	0	1.64	1.66	1.02	65	87	100
37	1.14	2.77	0	1.56	1.89	1.02	60	92	100
38	1.19	2.85	0.02	1.55	1.89	0.87	50	87	100
39	1.16	2.73	0.03	1.7	1.61	1	61	85	100
40	1.17	2.66	0.05	1.75	1.67	1.11	66	82	100
41	1.17	2.52	0.04	1.69	1.57	1.12	77	89	100
42	1.17	2.52	0.02	1.71	1.67	1.22	83	93	100
43	1.19	2.61	0.02	1.68	1.73	1.13	68	87	100
44	1.14	2.54	0.05	1.69	1.57	1.05	63	81	100

Table 2 continues. Seaming Parameters of 50 Non-Leakage Cans.

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
45	1.18	2.52	0.09	1.61	1.63	1.15	78	92	100
46	1.2	2.54	0.12	1.62	1.69	1.23	84	96	100
47	1.18	2.52	0.06	1.66	1.58	1.15	79	90	100
48	1.2	2.53	0.11	1.61	1.61	1.12	75	90	100
49	1.19	2.6	0.03	1.77	1.73	1.26	77	89	100
50	1.17	2.61	0.05	1.73	1.77	1.22	73	90	100
51	1.2	2.59	0.03	1.63	1.7	1.1	67	87	90
52	1.21	2.62	0.08	1.43	1.68	0.88	53	86	90
53	1.2	2.68	0.03	1.7	1.62	1	58	80	100
54	1.18	2.68	0.05	1.81	1.7	1.22	73	85	100
55	1.21	2.7	0.09	1.61	1.79	1.07	63	89	100
56	1.26	2.75	0.17	1.51	1.75	0.96	57	89	100
57	1.24	2.72	0.05	1.5	1.81	1	57	90	100
58	1.24	2.58	0.1	1.49	1.76	1.09	70	95	100
59	1.2	2.61	0.02	1.69	1.78	1.16	70	89	100
60	1.19	2.52	0.04	1.63	1.73	1.14	71	90	100
61	1.17	2.7	0	1.6	1.74	0.99	57	84	100
62	1.15	2.69	0.03	1.62	1.73	0.99	57	82	100
63	1.19	2.74	0.04	1.67	1.67	0.96	54	78	100
64	1.21	2.72	0.05	1.66	1.67	0.96	55	79	100

Table 2 continues. Seaming Parameters of 50 Non-Leakage Cans.

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
65	1.2	2.51	0.06	1.68	1.68	1.2	82	95	100
66	1.19	2.54	0.07	1.75	1.62	1.19	80	91	100
67	1.18	2.57	0.06	1.66	1.62	1.06	68	85	100
68	1.2	2.57	0.06	1.77	1.75	1.31	83	95	100
69	1.26	2.55	0.01	1.76	1.78	1.33	85	97	100
70	1.2	2.49	0	1.69	1.78	1.28	83	98	100
71	1.15	2.66	0.06	1.6	1.86	1.15	66	92	100
72	1.17	2.65	0.06	1.76	1.72	1.18	70	86	100
73	1.17	2.63	0	1.77	1.77	1.21	70	86	100
74	1.19	2.67	0	1.77	1.64	1.03	58	79	100
75	1.2	2.66	0.03	1.66	1.88	1.23	72	94	100
76	1.17	2.59	0.03	1.61	1.79	1.15	70	90	100
77	1.23	2.81	0.02	1.8	1.95	1.26	68	92	90
78	1.21	2.78	0.02	1.69	2.02	1.28	72	98	90
79	1.22	2.77	0.09	1.64	1.85	1.12	63	91	80
80	1.24	2.74	0.01	1.74	2.07	1.38	76	100	80
81	1.15	2.71	0.02	1.71	1.61	0.94	55	76	100
82	1.17	2.7	0.04	1.61	1.72	0.96	57	84	100
83	1.24	2.71	0.05	1.41	1.73	0.81	46	86	90
84	1.2	2.72	0.16	1.39	1.76	0.89	54	89	90

Table 2 continues. Seaming Parameters of 50 Non-Leakage Cans.

S.N.	ST (mm)	SH (mm)	SG (mm)	CH (mm)	BH (mm)	O (mm)	OR (%)	BHB (%)	TR (%)
85	1.2	2.6	0.08	1.65	1.58	1.02	64	81	100
86	1.2	2.59	0.14	1.62	1.54	1.03	68	83	100
87	1.2	2.64	0.13	1.65	1.61	1.05	67	84	100
88	1.17	2.68	0.13	1.65	1.5	0.93	56	75	100
89	1.16	2.61	0.02	1.5	1.71	0.93	55	87	100
90	1.18	2.61	0.03	1.52	1.7	0.97	58	87	100
91	1.21	2.58	0.06	1.65	1.62	1.03	61	81	90
92	1.21	2.62	0.08	1.74	1.79	1.26	74	91	90
93	1.25	2.73	0.06	1.74	1.91	1.27	72	94	90
94	1.19	2.75	0.06	1.84	1.92	1.34	74	92	90
95	1.25	2.49	0.13	1.53	1.57	1.07	74	90	90
96	1.2	2.56	0.12	1.55	1.73	1.14	73	95	90
97	1.17	2.73	0.01	1.7	1.95	1.23	69	94	100
98	1.21	2.76	0.02	1.46	2.01	1.02	55	94	100
99	1.18	2.64	0.03	1.68	1.84	1.22	72	93	100
100	1.2	2.68	0.03	1.74	1.85	1.25	70	90	100

In each case, 50 cans were tested and therefore 100 data were collected, as two cuts was made from a single can and two different readings were taken. After all the data has been gathered, the next step will be analysis of the data and finding out the major causes of the leakage problem.

4 Analysis and Findings

There are altogether eight different types of parameters that were measured for each group of leakage as well as non-leakage cans. The collected data of leakage cans, can be seen on Table 1 whereas the data of non-leakage cans, can be seen on Table 2. The first step of the analysis was to test all the different data sets in each case for normality to check the nature of the data and whether it follows a normal distribution or not. All the parameters of leakage cans were analysed through chi square test using excel to calculate the p-value and determine whether the data follows normal distribution or not.

The starting phase of calculation was to separate the thickness column in Table 1 to test only the data of seam thickness in leakage cans. After the column was separated, only the 'seam thickness' data of leakage cans were gathered. The next part was to obtain the basic information about the data such as sample size, minimum value, maximum value, mean and standard deviation with normal calculations. These information help to calculate the range, cell length, number of cells, corrected cell number and corrected cell length. After this beginning phase of calculation, a table is created for next phase of calculation with the rows according to the corrected cell number. There are six columns mainly cell start, cell end, probability, expected frequency, observed frequency and chi square value. The cell start value begins with the minimum value of the data set and cell end is the sum of cell start value on that row and the corrected cell length. The cell start at the next row is the same value as the cell end value of previous row and this process continues until the cell end value ends at maximum value of the data set. The probability value in each row is calculated by using normal distribution function with respect to cell end value and cell start value of the same row, using mean and standard deviation of the whole data set. The expected frequency (E) is calculated by multiplying the probability with the sample size. The observed frequency (F) is the actual number of data that are within the range of cell start value and cell end value. The chi squared value is calculated as the square of (E – F) and after it is squared, it is followed with division by E. The degree of freedom is one number less than the corrected number of cells. At last, the sum of all chi-squared values is calculated, and the p-value is obtained through the chi-squared function in excel with respect to the final sum of chi squared values and the degree of freedom. These processes are similar in every calculation shown from Table 3 to Table 18, to conduct chi squared test and obtain p-values.

First, the thickness of leakage cans was tested using excel and Table 3 shows the calculations to calculate p-value. As the P-value of thickness is very small than the significance value of 0.05, the assumed hypothesis of data sets following the normal distribution can be ruled out and concluded that the parameters of seam thickness does not follow the normal distribution in leakage cans.

Table 3. Calculations for Chi-squared test of seam thickness in leakage cans.

	Cell Start	**Cell End**	**Probability**	**Expected Frequency (E)**	**Observed Frequency (F)**	**Chi Square [(E-F) ^2/E]**
1st Cell	1.13	1.1575	0.1040718	10.40718228	6.00	1.866331842
2nd Cell	1.1575	1.185	0.1985849	19.85849435	30.00	5.179150803
3rd Cell	1.185	1.2125	0.2530191	25.30190549	41.00	9.739589426
4th Cell	1.2125	1.24	0.2152865	21.52864502	4.00	14.27184089
5th Cell	1.24	1.2675	0.1223192	12.23192308	8.00	1.464133878
6th Cell	1.2675	1.295	0.0463921	4.639208799	6.00	0.399152694
7th Cell	1.295	1.3225	0.011739	1.173897928	3.00	2.840663313
8th Cell	1.3225	1.35	0.0019804	0.198037097	2.00	16.396273
				Sum of Chi Square Value		52.15713585
				Degree of Freedom (DF)		7
				P - Value		**5.43666E-09**

Similarly, the seam height of the leakage cans was tested for normality and Table 4 shows the calculations done to calculate p-value using Excel. As the P-value of seam height is smaller than the significance value of 0.05, the data sets does not follow the normal distribution.

Table 4. Calculations for Chi-squared test of seam height in leakage cans.

	Cell Start	**Cell End**	**Probability**	**Expected Frequency (E)**	**Observed Frequency (F)**	**Chi Square [(E-F) ^2/E]**
1st Cell	2.54	2.575	0.0051621	0.516206516	1.00	0.45341569
2nd Cell	2.575	2.61	0.0293333	2.933328655	1.00	1.27423829
3rd Cell	2.61	2.645	0.1017464	10.17464485	7.00	0.99053776
4th Cell	2.645	2.68	0.2156865	21.56865418	19.00	0.30590617
5th Cell	2.68	2.715	0.27965	27.96499591	43.00	8.08336782
6th Cell	2.715	2.75	0.2218287	22.18287375	14.00	3.01851886
7th Cell	2.75	2.785	0.1076272	10.76271886	8.00	0.70917169
8th Cell	2.785	2.82	0.0319151	3.191511047	7.00	4.54474006
				Sum of Chi Square Value		19.3798963
				Degree of Freedom (DF)		7
				P - Value		**0.00707698**

The gap of the leakage cans was tested for normality and Table 5 shows the calculations done to calculate p-value using excel. As the P-value of gap is very small than the significance value of 0.05, we can deduce that the gap parameters does not follow the normal distribution.

Table 5. Calculations for Chi-squared test of seam gap in leakage cans.

	Cell Start	**Cell End**	**Probability**	**Expected Frequency (E)**	**Observed Frequency (F)**	**Chi Square [(E-F) ^2/E]**
1st Cell	0	0.0175	0.1758054	17.58053904	31.00	10.243254
2nd Cell	0.0175	0.035	0.2304763	23.04762612	41.00	13.983554
3rd Cell	0.035	0.0525	0.2143377	21.43376569	13.00	3.3185211
4th Cell	0.0525	0.07	0.1413961	14.13961357	3.00	8.7761232
5th Cell	0.07	0.0875	0.0661574	6.615740916	4.00	1.0342153
6th Cell	0.0875	0.105	0.0219486	2.194859228	4.00	1.4846206
7th Cell	0.105	0.1225	0.0051614	0.516135683	3.00	11.953411
8th Cell	0.1225	0.14	0.0008599	0.085991679	1.00	9.7150238
				Sum of Chi Square Value		60.508723
				Degree of Freedom (DF)		7
				P - Value		**1.195E-10**

Next, the parameters of cover hook were tested for normality and the calculations to calculate p-value can be seen in Table 6. As the P-value of cover hook is very small than the significance value of 0.05, we can deduce that the parameters does not follow the normal distribution.

Table 6. Calculations for Chi-squared test of cover hook in leakage cans.

	Cell Start	**Cell End**	**Probability**	**Expected Frequency (E)**	**Observed Frequency (F)**	**Chi Square [(E-F) ^2/E]**
1st Cell	1.32	1.3925	0.0109981	1.099812237	2.00	0.7367967
2nd Cell	1.3925	1.465	0.0333257	3.332573819	7.00	4.035924
3rd Cell	1.465	1.5375	0.0776158	7.761579106	11.00	1.3511902
4th Cell	1.5375	1.61	0.1389585	13.89585188	7.00	3.4220841
5th Cell	1.61	1.6825	0.1912602	19.12601935	5.00	10.433139
6th Cell	1.6825	1.755	0.2023907	20.23906508	17.00	0.5183808
7th Cell	1.755	1.8275	0.1646595	16.4659462	41.00	36.555433
8th Cell	1.8275	1.9	0.1029909	10.29909286	10.00	0.0086859
				Sum of Chi Square Value		57.061634
				Degree of Freedom (DF)		7
				P - Value		**5.811E-10**

Similarly, the parameters of body hook were also checked for normality test. The calculation part to calculate p-value can be clearly seen in Table 7. Here, the calculated P-value is smaller than the significance value of 0.05, it can be deduced that the parameters of body hook does not follow normal distribution in leakage cans.

Table 7. Calculations for Chi-squared test of body hook in leakage cans.

	Cell Start	**Cell End**	**Probability**	**Expected Frequency (E)**	**Observed Frequency (F)**	**Chi Square [(E-F) ^2/E]**
1st Cell	1.44	1.52625	0.0570667	5.706666743	8.00	0.921619864
2nd Cell	1.52625	1.6125	0.1123373	11.23373254	15.00	1.262694346
3rd Cell	1.6125	1.69875	0.1710822	17.10821605	17.00	0.000684508
4th Cell	1.69875	1.785	0.2015818	20.15817994	20.00	0.001241228
5th Cell	1.785	1.87125	0.1837699	18.3769935	15.00	0.620563155
6th Cell	1.87125	1.9575	0.1296189	12.96188511	5.00	4.890616911
7th Cell	1.9575	2.04375	0.070731	7.073103913	18.00	16.8804332

Table 7 continues. Calculations for Chi-squared test of body hook in leakage cans.

	Cell Start	Cell End	Probability	Expected Frequency (E)	Observed Frequency (F)	Chi Square [(E-F) ^2/E]
8th Cell	2.04375	2.13	0.0298581	2.985808683	2.00	0.325479246
				Sum of Chi Square Value		24.90333245
				Degree of Freedom (DF)		7
				P - Value		**0.000789328**

Next, the parameters of overlap percentage were checked for normality test and the calculations to calculate p-value can be seen on Table 8. Here, the calculated P-value is greater than the significance value of 0.05, it can be deduced that the parameters of body hook does follow the normal distribution in leakage cans.

Table 8. Calculations for Chi-squared test of overlap percentage in leakage cans.

	Cell Start	Cell End	Probability	Expected Frequency (E)	Observed Frequency (F)	Chi Square [(E-F) ^2/E]
1st Cell	38	43	0.00770766	0.770765552	2.00	1.96041108
2nd Cell	43	48	0.03385206	3.385206446	2.00	0.56681828
3rd Cell	48	53	0.09912671	9.91267087	8.00	0.3690539
4th Cell	53	58	0.1936398	19.3639805	21.00	0.13822364
5th Cell	58	63	0.25244442	25.24444205	19.00	1.54461946
6th Cell	63	68	0.21967117	21.96711653	27.00	1.15308334
7th Cell	68	73	0.12757928	12.75792844	16.00	0.82388203
8th Cell	73	78	0.04943658	4.943657951	5.00	0.00064212
				Sum of Chi Square Value		6.55673385
				Degree of Freedom (DF)		7
				P - Value		**0.47644184**

Similarly, the parameters of body hook butting percentage were also checked for normality test. The calculation part to calculate p-value can be clearly seen in Table 9. As the P-value of body hook butting is smaller than the significance value of 0.05, we can deduce that the parameters does not follow the normal distribution.

Table 9. Calculations for Chi-squared test of body hook butting in leakage cans.

	Cell Start	Cell End	Probability	Expected Frequency (E)	Observed Frequency (F)	Chi Square [(E-F) ^2/E]
1st Cell	67	71	0.03783305	3.783305194	7.00	2.73494337
2nd Cell	71	75	0.0774872	7.74872019	6.00	0.39464869
3rd Cell	75	79	0.12810285	12.81028486	14.00	0.11049107
4th Cell	79	83	0.17095279	17.09527877	17.00	0.00053103
5th Cell	83	87	0.18415897	18.41589698	15.00	0.63360216
6th Cell	87	91	0.16014435	16.01443543	18.00	0.24618206
7th Cell	91	95	0.11241577	11.24157721	5.00	3.46546444
8th Cell	95	99	0.06369812	6.369812457	18.00	21.2347323
				Sum of Chi Square Value		28.8205951
				Degree of Freedom (DF)		7
				P - Value		**0.000156**

At last, the parameters of tightness rating were checked for normality and the calculations to calculate p-value are shown in Table 10. Here, the p-value of tightness rating was extremely small than the significance value of 0.05 and it can be concluded that the parameters do not follow the normal distribution.

Table 10. Calculations for Chi-squared test of tightness rating in leakage cans.

	Cell Start	Cell End	Probability	Expected Frequency (E)	Observed Frequency (F)	Chi Square [(E-F) ^2/E]
1st Cell	70	73.75	0.00569349	0.569348728	6.00	51.79948907
2nd Cell	73.75	77.5	0.01562377	1.562376868	0.00	1.562376868
3rd Cell	77.5	81.25	0.0358755	3.587549648	8.00	5.427024019
4th Cell	81.25	85	0.06893368	6.89336805	0.00	6.89336805
5th Cell	85	88.75	0.11084086	11.08408593	0.00	11.08408593
6th Cell	88.75	92.5	0.14914651	14.91465138	16.00	0.078981506
7th Cell	92.5	96.25	0.167949	16.79489964	0.00	16.79489964
8th Cell	96.25	100	0.15826881	15.82688075	70.00	185.4267367
				Sum of Chi Square Value		279.0669618
				Degree of Freedom (DF)		7
				P - Value		**1.77539E-56**

Similarly, the parameters of the non-leakage cans were also tested out and undergone the same procedure of chi squared test using excel. The seam thickness data of non-leakage cans were initiated for calculation. After conducting out the chi-squared test as shown in Table 11, the p-value obtained was slightly smaller than the significance value of 0.05. So, the assumed hypothesis of data distributed into a normal distribution can be ruled out and concluded that the parameters of thickness does not follow a normal distribution in non-leakage cans.

Table 11. Calculations for Chi-squared test of seam thickness in non-leakage cans.

	Cell Start	**Cell End**	**Probability**	**Expected Frequency (E)**	**Observed Frequency (F)**	**Chi Square [(E-F) ^2/E]**
1st Cell	1.14	1.155	0.0531643	5.316432486	7.00	0.53313939
2nd Cell	1.155	1.17	0.1169681	11.69680593	5.00	3.83414155
3rd Cell	1.17	1.185	0.1884953	18.84953437	27.00	3.52422976
4th Cell	1.185	1.2	0.2225231	22.25231083	14.00	3.06038481
5th Cell	1.2	1.215	0.1924465	19.24465488	31.00	7.18059844
6th Cell	1.215	1.23	0.1219239	12.19238583	5.00	4.24284588
7th Cell	1.23	1.245	0.0565794	5.657940049	6.00	0.02067979
8th Cell	1.245	1.26	0.019228	1.922797103	5.00	4.92468896
				Sum of Chi Square Value		27.3207086
				Degree of Freedom (DF)		7
				P - Value		0.00029176

After conducting out the chi-squared test as shown in Table 12, the p-value obtained was larger than the significance value of 0.05. So, the assumed hypothesis of data distributed into a normal distribution can be accepted and concluded that the parameters of seam height follow a normal distribution in non-leakage cans.

Table 12. Calculations for Chi-squared test of seam height in non-leakage cans.

	Cell Start	**Cell End**	**Probability**	**Expected Frequency (E)**	**Observed Frequency (F)**	**Chi Square [(E-F) ^2/E]**
1st Cell	2.49	2.54	0.0561601	5.616009525	10.00	3.42224713
2nd Cell	2.535	2.58	0.1133598	11.33598036	10.00	0.15744942
3rd Cell	2.58	2.63	0.1749226	17.49225895	23.00	1.73420778
4th Cell	2.625	2.67	0.2063574	20.63574143	12.00	3.6139254
5th Cell	2.67	2.72	0.1861204	18.61203673	18.00	0.02012617
6th Cell	2.715	2.76	0.1283393	12.8339307	14.00	0.10594709
7th Cell	2.76	2.81	0.0676535	6.76534706	9.00	0.73812529
8th Cell	2.805	2.85	0.0272608	2.726082321	4.00	0.5953108
				Sum of Chi Square Value		10.3873391
				Degree of Freedom (DF)		7
				P - Value		0.1676651

After conducting out the chi-squared test as shown in Table 13, the p-value obtained was very small than the significance value of 0.05. So, the assumed hypothesis of data distributed into a normal distribution can be completely ruled out and concluded that the parameters of gap does not follow a normal distribution in non-leakage cans.

Table 13. Calculations for Chi-squared test of seam gap in non-leakage cans.

	Cell Start	**Cell End**	**Probability**	**Expected Frequency (E)**	**Observed Frequency (F)**	**Chi Square [(E-F) ^2/E]**
1st Cell	0	0.021	0.1394922	13.94922049	38.00	41.4675497
2nd Cell	0.021	0.043	0.1966422	19.66421941	19.00	0.02243605
3rd Cell	0.043	0.064	0.2092594	20.92593645	18.00	0.40911451
4th Cell	0.064	0.085	0.1681047	16.8104695	9.00	3.6288953
5th Cell	0.085	0.106	0.1019396	10.19395774	5.00	2.6463909
6th Cell	0.106	0.128	0.0466586	4.665861387	4.00	0.09502455
7th Cell	0.128	0.149	0.016117	1.611695825	5.00	7.12330764
8th Cell	0.149	0.17	0.0042006	0.420061964	2.00	5.94246661
				Sum of Chi Square Value		61.3351853
				Degree of Freedom (DF)		7
				P - Value		8.1661E-11

After conducting out the chi-squared test as shown in Table 14, the p-value obtained was larger than the significance value of 0.05. So, the assumed hypothesis of data distributed into a normal distribution can be accepted and concluded that the parameters of cover hook follow a normal distribution in non-leakage cans.

Table 14. Calculations for Chi-squared test of cover hook in non-leakage cans.

	Cell Start	Cell End	Probability	Expected Frequency (E)	Observed Frequency (F)	Chi Square [(E-F) ^2/E]
1st Cell	1.33	1.4	0.008029	0.802901208	3.00	6.01225039
2nd Cell	1.4	1.47	0.0333161	3.331610449	3.00	0.03300671
3rd Cell	1.47	1.54	0.0944866	9.448663865	8.00	0.22210833
4th Cell	1.54	1.61	0.1832383	18.32383116	9.00	4.74430411
5th Cell	1.61	1.68	0.243069	24.30689776	27.00	0.29838442
6th Cell	1.68	1.75	0.2205823	22.05822918	26.00	0.70438824
7th Cell	1.75	1.82	0.1369363	13.69363383	18.00	1.35426358
8th Cell	1.82	1.89	0.0581397	5.813971583	6.00	0.00595231
				Sum of Chi Square Value		13.3746581
				Degree of Freedom (DF)		7
				P - Value		0.06348929

After conducting out the chi-squared test as shown in Table 15, the p-value obtained was larger than the significance value of 0.05. So, the assumed hypothesis of data distributed into a normal distribution can be accepted and concluded that the parameters of body hook follow a normal distribution in non-leakage cans.

Table 15. Calculations for Chi-squared test of body hook in non-leakage cans.

	Cell Start	Cell End	Probability	Expected Frequency (E)	Observed Frequency (F)	Chi Square [(E-F) ^2/E]
1st Cell	1.5	1.57	0.0619941	6.199411466	8.00	0.522972073
2nd Cell	1.57	1.64	0.1274927	12.74926779	19.00	3.064619381
3rd Cell	1.64	1.71	0.1940224	19.40224378	15.00	0.998840676
4th Cell	1.71	1.79	0.2185216	21.85215739	25.00	0.453452395
5th Cell	1.79	1.86	0.1821482	18.21481971	16.00	0.269309629
6th Cell	1.86	1.93	0.1123633	11.23632909	7.00	1.597183924
7th Cell	1.93	2	0.0512912	5.129121432	5.00	0.003250526

Table 15 continues. Calculations for Chi-squared test of body hook in non-leakage cans.

	Cell Start	**Cell End**	**Probability**	**Expected Frequency (E)**	**Observed Frequency (F)**	**Chi Square [(E-F) ^2/E]**
8th Cell	2	2.07	0.0173221	1.732214544	5.00	6.164606934
				Sum of Chi Square Value		13.07423554
				Degree of Freedom (DF)		7
				P - Value		0.070320181

After conducting out the chi-squared test as shown in Table 16, the p-value obtained was larger than the significance value of 0.05. So, the assumed hypothesis of data distributed into a normal distribution can be accepted and concluded that the parameters of overlap percentage follow a normal distribution in non-leakage cans.

Table 16. Calculations for Chi-squared test of overlap percentage in non-leakage cans.

	Cell Start	**Cell End**	**Probability**	**Expected Frequency (E)**	**Observed Frequency (F)**	**Chi Square [(E-F) ^2/E]**
1st Cell	35	41.25	0.004046	0.404602267	1.00	0.87616528
2nd Cell	41.3	47.5	0.0208192	2.081920699	2.00	0.00322347
3rd Cell	47.5	53.75	0.0710703	7.107029248	3.00	2.37338115
4th Cell	53.8	60	0.1610625	16.1062498	23.00	2.95064292
5th Cell	60	66.25	0.2424337	24.24336847	16.00	2.80295718
6th Cell	66.3	72.5	0.2424337	24.24336847	30.00	1.36692253
7th Cell	72.5	78.75	0.1610625	16.1062498	15.00	0.07598222
8th Cell	78.8	85	0.0710703	7.107029248	10.00	1.17760593
				Sum of Chi Square Value		11.6268807
				Degree of Freedom (DF)		7
				P - Value		0.11351621

After conducting out the chi-squared test as shown in Table 17, the p-value obtained was larger than the significance value of 0.05. So, the assumed hypothesis of data distributed into a normal distribution can be accepted and concluded that the parameters of body hook butting percentage follow a normal distribution in non-leakage cans.

Table 17. Calculations for Chi-squared test of body hook butting in non-leakage cans.

	Cell Start	Cell End	Probability	Expected Frequency (E)	Observed Frequency (F)	Chi Square [(E-F) ^2/E]
1st Cell	75	78.1	0.0343503	3.435031168	7.00	3.69982168
2nd Cell	78.13	81.3	0.0818297	8.18296957	9.00	0.08157659
3rd Cell	81.25	84.4	0.1473454	14.7345434	11.00	0.94653862
4th Cell	84.38	87.5	0.2005655	20.05654742	21.00	0.04437966
5th Cell	87.5	90.6	0.2063931	20.63931291	18.00	0.33750991
6th Cell	90.63	93.8	0.160567	16.05669956	15.00	0.06954194
7th Cell	93.75	96.9	0.0944318	9.443179236	14.00	2.19890092
8th Cell	96.88	100	0.0419795	4.197950467	5.00	0.1532375
				Sum of Chi Square Value		7.53150681
				Degree of Freedom (DF)		7
				P - Value		0.37570909

After conducting out the chi-squared test as shown in Table 18, the p-value obtained was extremely less than the significance value of 0.05. So, the assumed hypothesis of data distributed into a normal distribution can be ruled out and concluded that the parameters of tightness rating does not follow a normal distribution in non-leakage cans.

Table 18. Calculations for Chi-squared test of seam thickness in non-leakage cans.

	Cell Start	Cell End	Probability	Expected Frequency (E)	Observed Frequency (F)	Chi Square [(E-F) ^2/E]
1st Cell	80	82.5	0.0002508	0.025077911	2.00	155.527998
2nd Cell	82.5	85	0.0016302	0.163023591	0.00	0.16302359
3rd Cell	85	87.5	0.0078309	0.783089247	0.00	0.78308925
4th Cell	87.5	90	0.0278042	2.780422628	0.00	2.78042263
5th Cell	90	92.5	0.0729907	7.299067591	16.00	10.3720405
6th Cell	92.5	95	0.141702	14.17020063	0.00	14.1702006
7th Cell	95	97.5	0.203472	20.34719782	0.00	20.3471978
8th Cell	97.5	100	0.2161181	21.61181366	82.00	168.737946
				Sum of Chi Square Value		372.881918
				Degree of Freedom (DF)		7
				P - Value		1.55E-76

From the chi-squared analysis to obtain the information about normality test of all the parameters of leakage and non-leakage cans, it is found that that the parameters of leakage cans do not follow a normal distribution. This means that the data are heavily distributed to the right or left rather than the centre. The reason for this might be that the leakage occurs only when the parameters are too low or too high than the required normal range of accepted parameters. The only parameter that was found normally distributed in leakage cans was the overlap percentage. Overlap percentage is not an individual parameter, but it is a calculation of ratio between the body hook, cover hook and the free space between seam formation. Also, the mean of the overlap ratio was found similar between the leakage and non-leakage cans. This suggests that the overlap ratio may not be directly linked with the occurrence of leakages in these cases.

Analysing with the non-leakage cans, the parameters of seam thickness, gap and tightness rating did not follow the normal distribution and the remaining all five parameters followed the normal distribution. In the case of gap, the seaming procedure always aims to achieve the near zero gap strategy to stop the leakage. So, most of the data falls around the zero mark and few data deviate away. This makes the distribution towards left oriented in both the cases of leakage and non-leakage cans and hence the normal distribution is not achieved. The similar is the case of tightness rating. The seaming procedure always aims to achieve the 100% tightness rating as it is a recommend seaming procedure to control leakage. So, most of the data falls around the 100 mark and only few data deviate away from 100. This makes the distribution towards right oriented in both the cases of leakage and non-leakage cans and hence the normal distribution is not achieved. In the case of seam thickness in non-leakage cans, the data tends to appear normally distributed but slightly heavier at the left side. For more visualization and comparison, bar-diagram and graph plotting will be conducted.

Observing the bar diagram of seam thickness data in Figure 20, the data of leakage cans seems far more deviated than the mean value of 1.20. Also, the data distribution is heavily on the left side in case of leakage cans whereas the data is distributed more on the centre area in case of non-leakage cans. As the thickness increases, the space between the cover hook and body hook also increases and chances of leakage occurring also increases. Leakage also occurs if the seam thickness is too low. This results in too much pressing of body hook and cover hook and leads to internal fracture resulting in instant leakage. Thus, there is not any data of seam thickness lower than 1.10 mm as it is the minimum requirement.

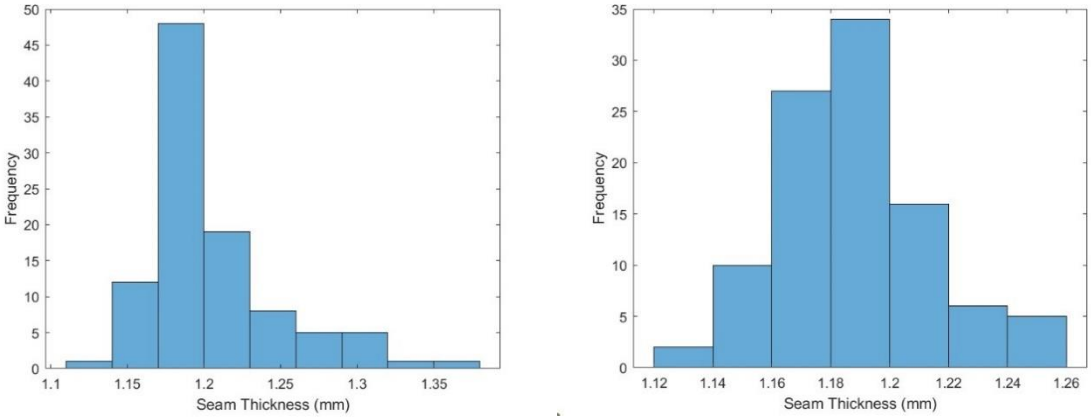


Figure 20. Bar-diagram of seam thickness in leakage (left) and non-leakage cans (right).

As seen in Figure 21, the difference between the seam thickness of leakage cans and non-leakage cans are highly noticeable. There are some sharp peaks in case of leakage cans which indicates the high seam thickness and probably the main cause of leakage in those cases. From both the diagram, it is safe to conclude that the seam thickness should be kept within the range of 1.12 - 1.22 mm as majority of the data in non-leakage cans are within that range.

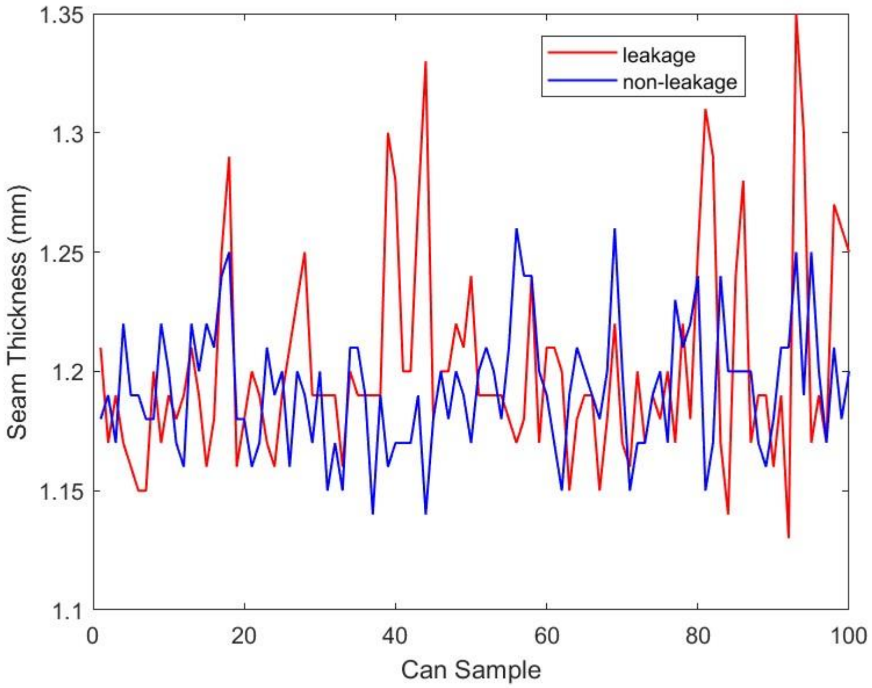


Figure 21. Graph plotting of thickness data in leakage and non-leakage cans.

While observing the bar-diagram of seam height in both leakage and non-leakage cans as shown in figure 22, the data of leakage cans shows a major peak at the centre between the 2.65 to 2.73 range, whereas the data of non-leakage cans shows a uniformly distributed data with majority occurring around the mean value of 2.65.

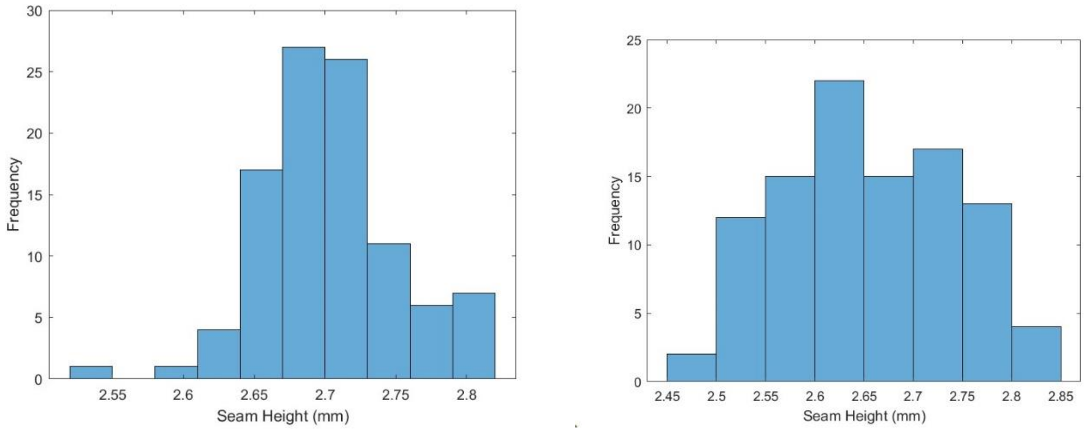


Figure 22. Bar-diagram of seam height in leakage cans (left) and non-leakage cans (right).

Studying the graph plotting of seam height data in leakage and non-leakage cans as shown in figure 23, it is found out that most of the data of non-leakage cans lies below 2.75 mm. From both diagrams, the significant difference is that more than half of the data lies below 2.65 mm in non-leakage cans whereas there are negligible data below 2.65 mm in case of leakage cans. So, it would be safe to conclude that the parameters of seam height should be kept within the range of 2.50 mm to 2.75 mm as most of the non-leakage data are within these range. The leakage cans, whose parameters of seam height falls within this range, their causes of leakage could be possibly due to other seaming parameters.

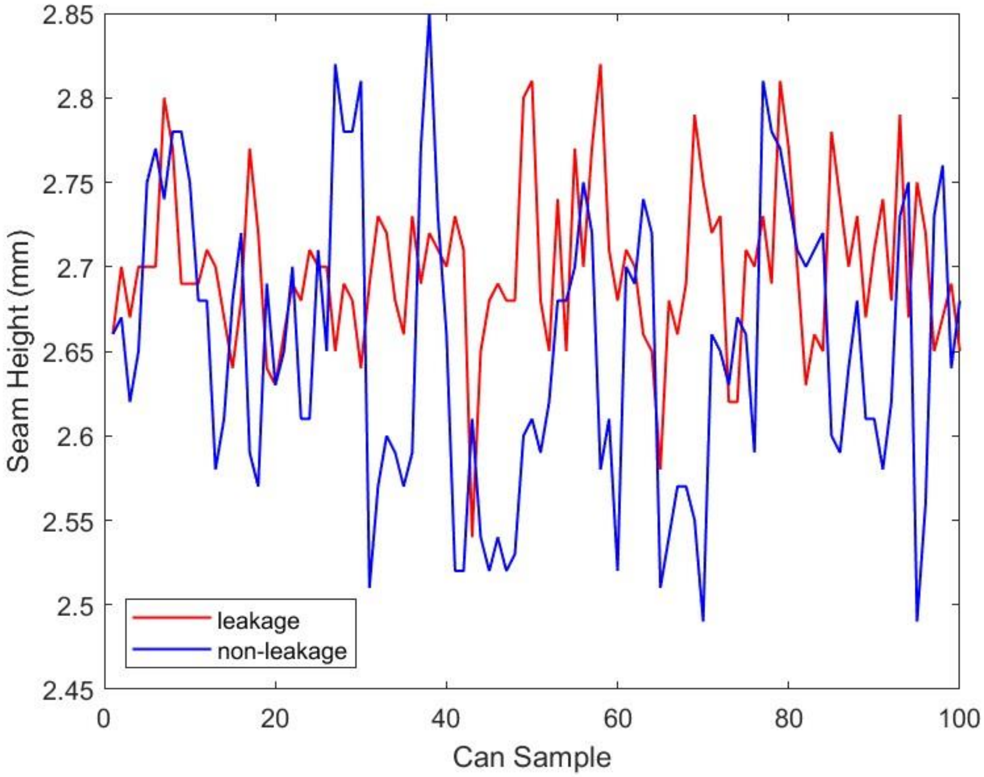


Figure 23. Graph plotting of seam height data in leakage and non-leakage cans.

While observing the bar-diagram in figure 24, most of the data of leakage cans falls to the right side in the range of 1.70 mm to 1.90 mm, whereas the data of non-leakage cans shows a normal distribution curve shape with high peak around the region of mean value of 1.66 mm. Shorter cover hook means there will not be enough grip between the cover hook and body hook and may result in leakage. Also, if the cover hook is too high, it may cause internal fracture within the seam resulting in leakage and beverage contamination with metal parts.

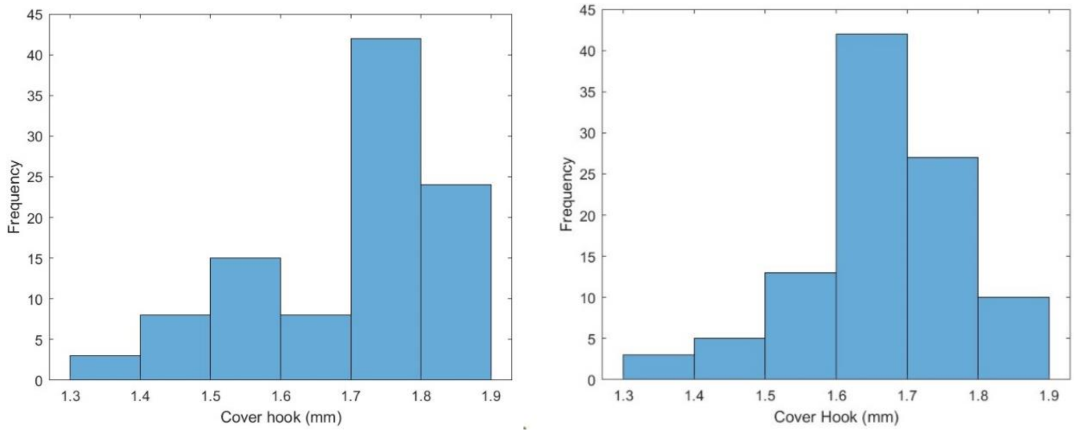


Figure 24. Bar-diagram of cover hook in leakage cans (left) and non-leakage cans (right).

From the graph plotting of cover hook data as shown in figure 25, the data of leakage cans are more deviated and forms more sharp peaks at both higher and lower sides. In case of non-leakage cans, there are some exceptions of sharp peaks but most of the data are consistent and falls within the range of 1.60 to 1.80. Studying both the diagram, the range of 1.50 mm to 1.80 mm is safer for the cover hook to prevent any leakage occurring in cans.

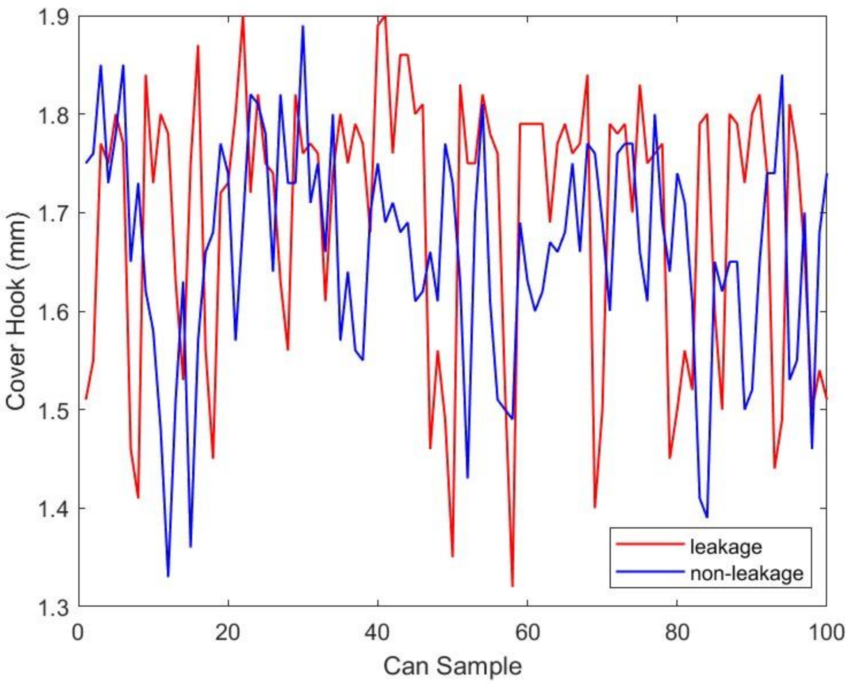


Figure 25. Graph plotting of cover hook data in leakage and non-leakage cans.

Observing the bar-diagram in figure 26, both the data looks similar in shape, but leakage cans data are more distributed and contains greater range. In case of non-leakage cans, the data is normally distributed with most of the data falling within the region of mean value of 1.74 mm. Like cover hook, body hook also should not be neither too long nor too short.

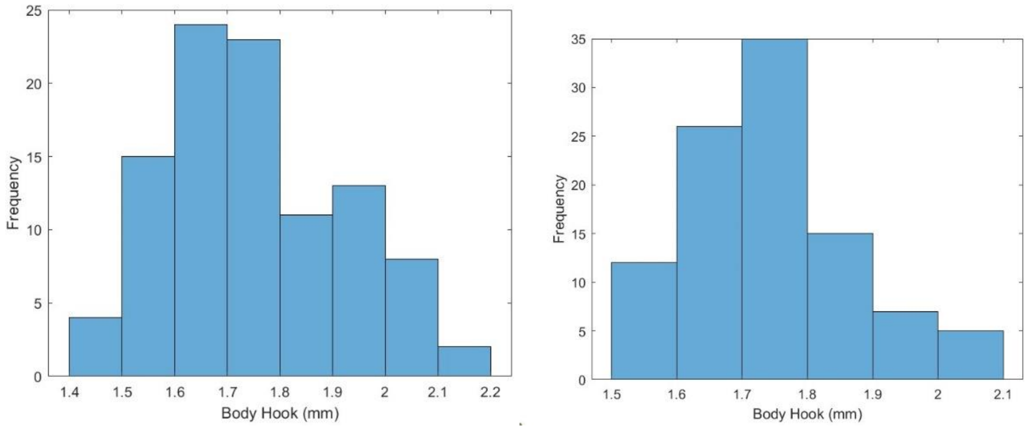


Figure 26. Bar-diagram of body hook in leakage cans (left) and non-leakage cans (right).

The graph plotting of body hook as shown in figure 27 describes how much the data of leakage cans are deviated whereas the non-leakage cans don’t show that many steep rise and fall. Overall, from both the diagrams, the range of 1.50 mm to 1.90 mm is safe for body hook parameters to prevent any leakages from occurring in cans.

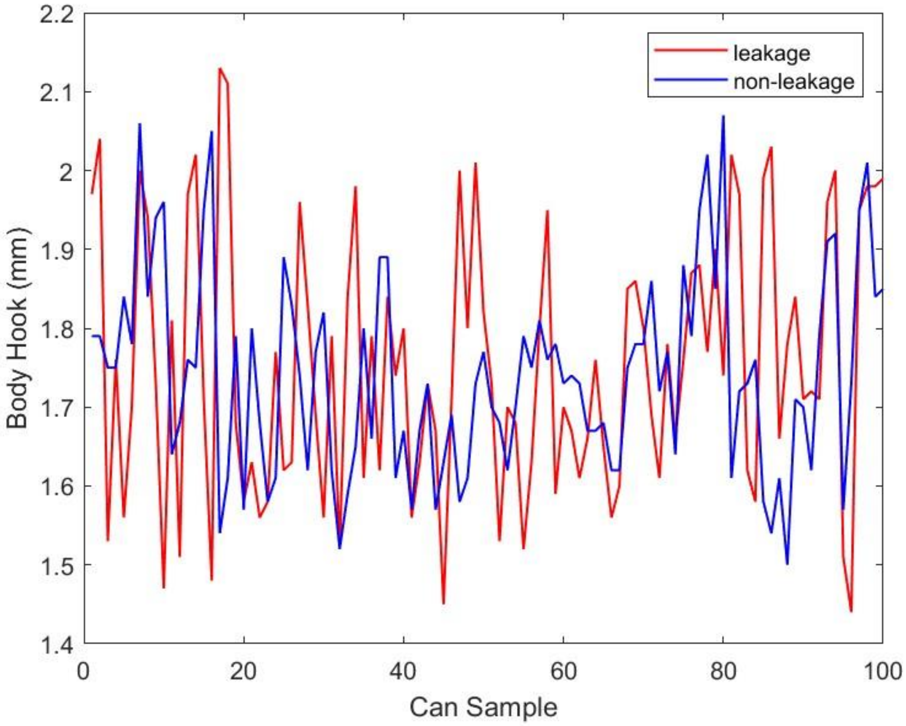


Figure 27. Graph plotting of body hook data in leakage and non-leakage cans.

The bar-diagram in figure 28 shows a significant difference between the data of leakage cans and non-leakage cans. In case of non-leakage cans, most of the data falls in the range of 80 to 95 with a mean value of 88%, whereas in case of leakage cans, a good amount of data is distributed below 80% and above 95%.

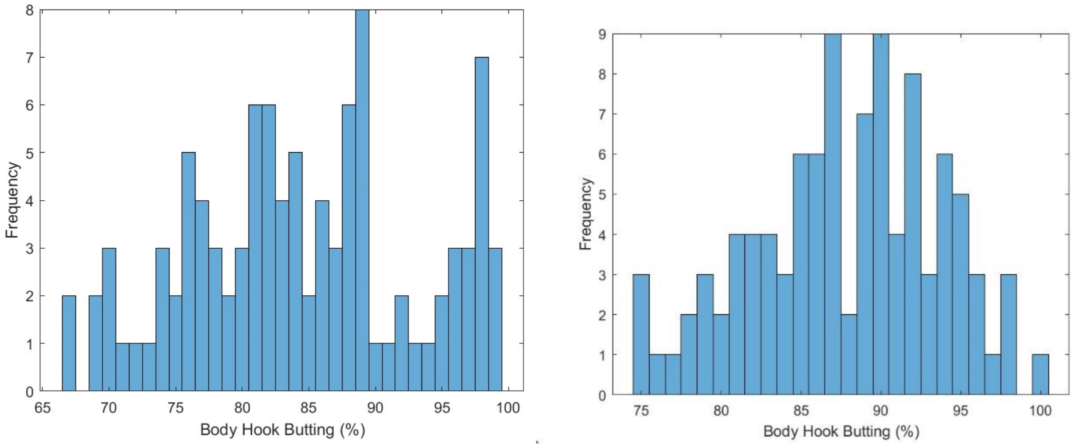


Figure 28. Bar-diagram of body hook butting in leakage (left) and non-leakage cans (right).

While observing the graph plotting of body hook butting data in figure 29, several sharp peaks downwards can be seen for the leakage cans. From both the diagrams, it is visible that the data ranges from 80 % to 95 % body hook butting, can be considered safe from occurring leakages in cans.

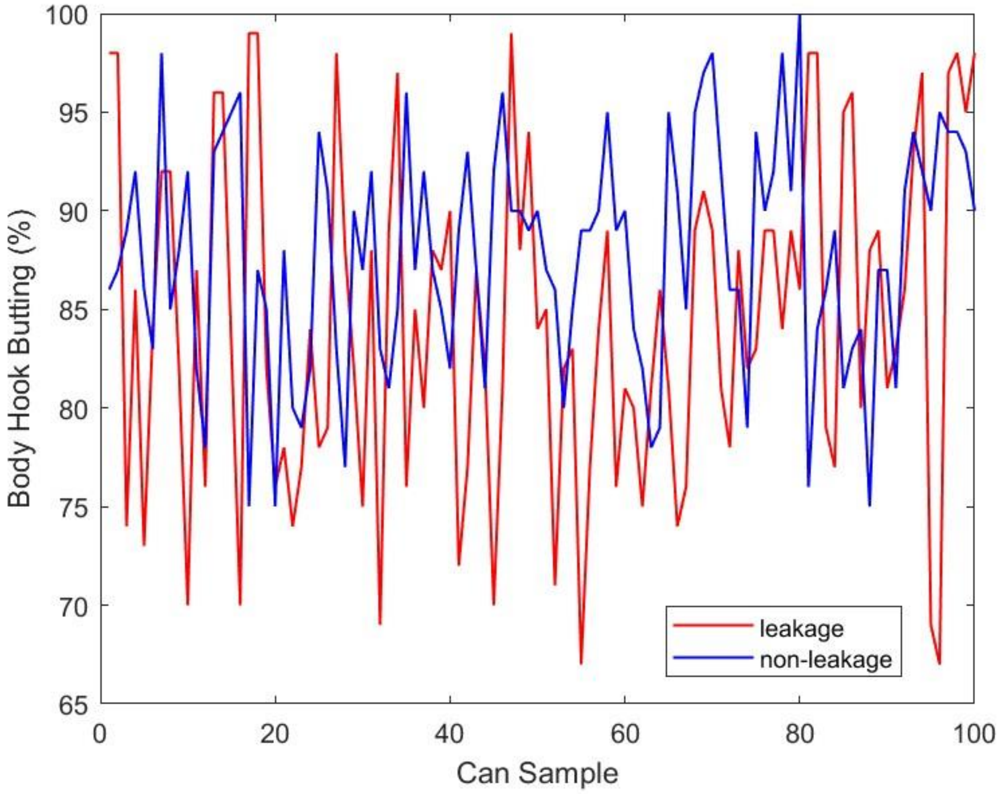


Figure 29. Graph plotting of body hook butting data in leakage and non-leakage cans.

While observing the bar-diagram as shown in figure 30, there is not any significant difference visible with both the diagrams of leakage and non-leakage cans. There are some slight differences like more data on below 55 % in leakage cans compared to non-leakage cans, very less data on above 75 % in leakage cans compared to non-leakage cans.

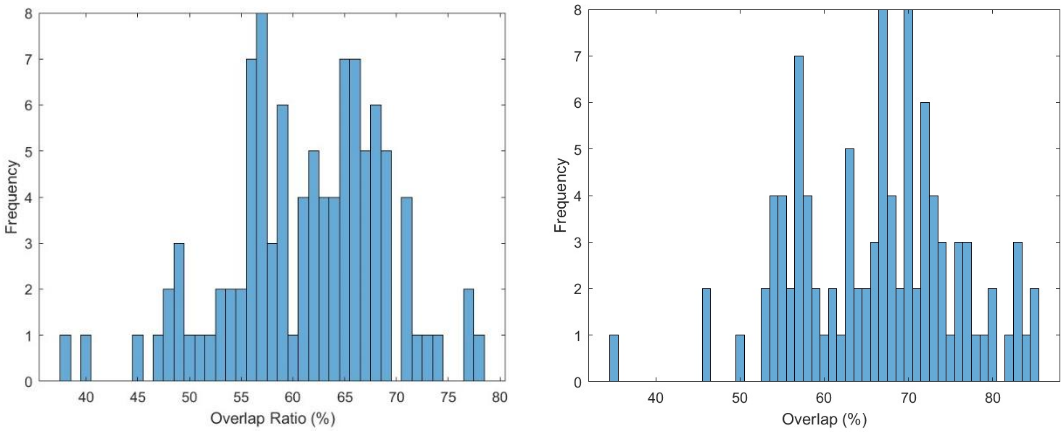


Figure 30. Bar-diagram of overlap ratio in leakage cans (left) and non-leakage cans (right).

The graph plotting on figure 31 shows the data of non-leakage cans situated in the upward region than the non-leakage cans. From both diagrams, it can be concluded that lower the overlap percentage, higher the chance of leakage. So, the range of 57% to 85% overlap ratio can be considered safe as majority of non-leakage cans data are within this range.

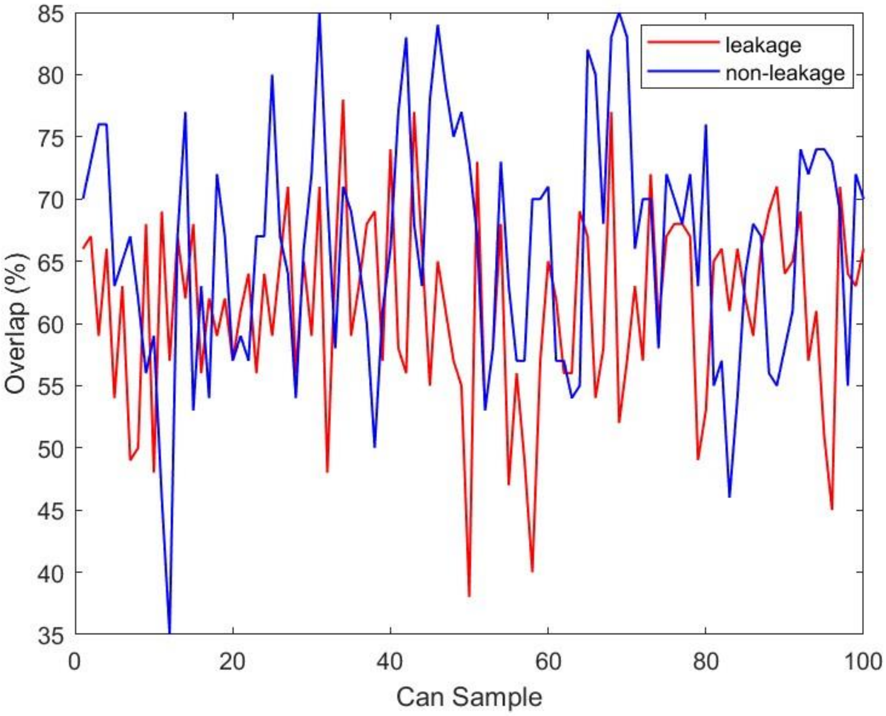


Figure 31. Graph plotting of overlap ratio data in leakage and non-leakage cans.

Table 19 shows the analysed range of acceptable parameters that assures the prevention of leakage from occurring in cans. If all the parameters of the can seam are well within their respective ranges as shown in Table 19, the chances of leakage occurring in cans will be negligible.

Table 19. Acceptable range of all the seaming parameters after the analysis.

Seaming Parameters	**Acceptable Range**
Seam Thickness	1.12 mm - 1.22 mm
Seam Height	2.50 mm - 2.75 mm
Gap	Maximum of 0.10 mm
Cover Hook	1.50 mm - 1.80 mm
Body Hook	1.50 mm - 1.90 mm
Overlap Ratio	57 % - 85 %
Body Hook Butting	80 % - 95 %
Tightness Rating	100% (wrinkle free)

The parameters of gap and tightness rating were not included in this bar-diagram and graph plotting analysis as it was clear from the chi-square distribution test. The target of tightness rating is always 100% which means that the cover hook should be wrinkle free to achieve a good quality seam. The target of seam gap should always be near zero with a maximum value of 0.10mm for a good quality seam. These are universally accepted guidelines for any type of seam. Also, from the chi-square distribution test, nearly all the data of gap and tightness rating were found in those range, in case of non-leakage cans. With the help of this analysis, a good quality seam will be achieved in the can seaming process that guarantees the prevention of leakages and reduce the product rejection rate.

5 Discussion

The main goal of this thesis is to analyse the leakage occurring problem in cans and help solve the problem. From the analysis, the acceptable range of seaming parameters was obtained at which the leakage does not occur in cans. This section will discuss the procedure to get the acceptable seaming parameters, reasons for seaming parameters getting out of range, problems faced during seaming and solutions for the problems.

5.1 Seaming operation setup

To get a good quality seam, it must be assured that the seaming rollers and chuck are proper. The chuck size should match with the type of lid being used. The seaming rollers should be easily rotating with negligible axial play and made sure that the correct first and second operation rollers are being used. Usually, the first operation roller has deep groove than the second operation roller. Proper monitoring should be done on a regular basis if the chucks and rollers are worn out or damaged. To begin with the seaming operation setup, pin height measurement should be considered. Pin height is the distance between the tip of the chuck lip and the seamer lift cylinder top surface. Pin height measurement is different for different types of can heights. Accurate measurements should be taken, and pin height should be corrected according to the required measurement, by adjusting the seamer height.

The calculation of pin height is done according to the given equation:

$$\text{Pin Height} = TH - CD - ts \tag{4}$$

Where, TH = Total Height of an empty can,

CD = Countersink Depth of the lid,

ts = Spring-Force Tolerance of about 1mm

A fixed height gauge can be made according to the known measurement of pin height and that gauge can be put between the chuck and the lift cylinder to setup the pin height in an easier way. Figure 32 shows a fixed gauge measuring the pin height by checking the gap between the chuck and the gauge. This ensures if the pin height is okay or not. Incorrect pin height may lead to high or low body hook and high seam gap. This will eventually lead to the occurrence of leakages in cans.

Figure 32. Measuring the pin height.

Once the pin height is correctly set, next is the spring force. There should be enough spring force in the seamer lift cylinder, so that required pressure is applied to the can from bottom during the seaming operation. The lift cylinder spring pressure is set to a maximum of 40 kg. If there is not enough spring pressure from the bottom, there will be no full grip within the chuck and the lid which results in improper seaming and incorrect seaming procedures. Spring force can be checked with a spring force gauge and if found incorrect spring force, springs in a lift cylinder can be changed with a correct spring.

After the pin height and lift cylinder pressure are okay, it is the turn of seaming rollers. The first operation seaming rollers should be setup at beginning. The height of the rollers with respect to the chuck should be noted and should be adjusted with a correct height of 0.01-0.02 mm. At the first marking station, the gap between the first operation roller and chuck is set at 0.60 mm. After setting the first operation rollers, seam profiles are to be checked and if the seam profiles are correct then the second operation rollers should be setup. If the seam profiles are incorrect, the height of the roller with respect to chuck should be checked and gap between the rollers and chucks should be checked again. The second operation rollers height with respect to the chuck should also be maintained with a correct height while fitting. At the second marking station, the gap between chuck and second operation rollers is set at 0.50 mm. After this, the seaming operation setup is complete, and cans are undergone through seaming procedures and taken to lab for seam inspection. If all the procedures of seaming operation setup are strictly followed and correct measurements are taken at every step, it ensures the seaming operation will be correctly conducted and the seaming parameters will fall within the correct range.

5.2 Causes of Incorrect Seaming Parameters

The main cause of seaming parameters getting out of range is seaming operations not set up correctly. Most of the time, the gap between the seaming rollers and chuck needs to be realigned to make a good seam formation and match the range of acceptable seaming parameters. There are several checklists provided by seamer manufacturing companies or can manufacturing companies that helps in finding the areas to look for if the specific parameters are out of range. For example, if the seam gap is too high, the probable causes according to the checklist provided by can manufacturing company ‘Ball Corporation’ are:

- Seaming rollers being higher relative to chuck.
- Incorrect seaming chuck being used.
- Incorrect Pin height set up.
- Lifter Spring force set too low.
- First operation roller too loose.
- Second operation roller too loose.

This type of seaming guidelines helps to troubleshoot the problem and narrow down the specific causes for such type of problem occurring. This type of guidelines only helps if the problem is associated with the seaming operations setup.

Apart from seaming operations being set incorrectly, there are other causes that leads to the seaming parameters being out of range. The occurrence of axial play in rollers due to the bearing being worn out or damaged is one of the causes for incorrect seaming parameters. The seaming rollers continuously operate at a higher speed for seaming hundreds of cans per minute and experience a greater load on the bearing over time. The same is with the case of chuck shaft bearings. The chuck shaft in the seamer is supported by bearings and the bottom bearing in the shaft needs to withstand a huge force which is also pushed by the lifter spring force. Over the time, the bearings get damaged and the axial and radial play is induced in the shaft. Figure 33 shows the disassembling of chuck shaft along with the bearing for replacing the damaged bearings. This induced play in shaft compromises the smooth operation of seaming and results in incorrect seaming parameters.

Figure 33. Disassembling the chuck shaft from seamer.

So, it is important to inspect the condition of seamer and rollers at a regular interval and plan the maintenance work. Another cause of seaming parameters being out of range is the inappropriate flange curl or slight damage of empty cans in the flange area. Damaged lids can also be the cause for inappropriate seaming formation. Thus, it is necessary to check and prevent every loophole that obstruct a good seam formation.

5.3 Solution to the Leakage Problem

After the analysation of leakage and non-leakage cans that were experimented, the accepted range of parameters were obtained containing the maximum range of data from non-leakage cans. The observed values of seaming parameters of both leakage as well as non-leakage cans were considered and the data which falls in the acceptable range were put into the Table 20 for comparison and differences were obtained as shown in the table.

Table 20. Comparison of observed seaming parameters within the acceptable range.

Seaming Parameters	**Acceptable Range**	**Non-Leakage Cans**	**Leakage Cans**	**Difference**
Seam Thickness	1.12 mm - 1.22 mm	89	71	18
Seam Height	2.50 mm - 2.75 mm	85	87	-2
Gap	0.00 mm - 0.10 mm	89	96	-7
Cover Hook	1.50 mm - 1.80 mm	84	82	2
Body Hook	1.50 mm - 1.90 mm	88	73	15
Overlap Ratio	57 % - 85 %	84	75	9
Body Hook Butting	80 % - 95 %	82	55	27
Tightness Rating	100% (wrinkle free)	82	70	12

After the comparison, it was found that most of the difference was found in the body hook butting percentage. In leakage cans, 45 parameters were out of range from 100 parameters of body hook butting. Also, the third most difference was found in body hook. So, it can be considered that most of the problems of leakage occurred due to the incorrect body hook. The second most difference came from the seam thickness parameters with difference of 18. In leakage cans, 29 parameters were out of range from 100 parameters of seam thickness.

Lastly, tightness rating parameters were out of range in 30 parameters out of 100 parameters. Thus, the main problem of leakage cans was mainly leading to the incorrect body hook and subsequently leading to the incorrect seam thickness and not acceptable tightness rating. Overall, the remaining other parameters were well within the range and not found any significant difference.

The main reason for the long body hook is lifter spring force set too high or short pin height taken during initial seaming operation setup. For the short body hook, the lifter spring might be set too low, or the pin height is longer than the actual height. The first operation roller set too tight, and the axial play induced in the chuck shaft can also lead to shorter body hook. So, the lifter spring force should be adjusted as such that the body hook neither becomes too short nor too long. Also, the pin height should be accurately taken and adjust if the body hook falls correctly within the range. Apart from these, the chuck shafts should be checked for induced play at a regular interval of time. Correcting the body hook makes sure that the body hook butting also comes within the acceptable range. So, adjusting the lifter spring force and pin height could solve half of the leakage occurring problem.

The problem of seam thickness is directly linked with the gap between seaming rollers and the chuck. If the seam thickness is less, the gap between the second operation roller and chuck should be increased and vice versa. The problem of wrinkles occurring, or less than 100% tightness rating is caused by incorrect pin height, incorrect first operation setting or bearing issues related to shafts or rollers. Incorrect first operation can be solved be readjusting the roller height with respect to the chuck and adjusting the gap between the first operation roller and chuck at the first marking station. Then the seam formation can be checked with a seam view machine and readjust the seaming setting if the seam formation is not good enough.

In conclusion, the most important parameters to look out for were found to be body hook, seam thickness and tightness rating. To control the leakage problem, the accurate pin height setting could solve most of the problem. Also, the adequate lifter spring force should be set such that acceptable body hook could be formed. The gap between the second operation roller and chuck should be set such that seam thickness is neither too high nor too low. The first operation roller setting should be done correctly so that the lid curl is formed correctly. Lastly, the condition of bearings should be properly checked so that the induced play in the roller and chuck shaft is negligible.

6 Conclusions

This study was based on leakage problem from the seam area of a beverage can. The experimentation was done, and comparative analysis was well conducted between the leakage cans and non-leakage cans. The main objective of finding out the root causes of leakage problem was well identified. The double seam technology was studied, and each seaming parameters associated with it were fully acknowledged. After the experimentation, significant differences were found between the seaming parameters of leakage and non-leakage cans. The acceptable range for each seaming parameters at which the leakage does not occur, were found out. The leakage cans were further analysed, and the critical parameters associated with the cause of the leakage problems were identified. The ‘body hook’ parameter was recognized to be the major cause of the leakage problem. ‘Seam thickness’ and ‘tightness rating’ also responsible for leakages in remaining cases. Feasible solutions to counter the problems and make those parameters within the range were discussed. The accurate pin height taken during seamer operation setting could hugely reduce the leakage problem. Other solution on seamer operation setting and seamer maintenance should be regularly maintained and supervised for further stoppage of leakage problem in future.

The demand of can beverages in growing exponentially and to meet such demand, lots of can manufacturing companies and beverage production companies are also growing. The aluminium can package is preferred over plastic bottles mainly for the environmental sustainability as the aluminium cans are 100% recyclable. Along with the recyclability, aluminium cans are lightweight, durable, classy in look and feels comfortable while holding which are all beneficial to customers. So, billions of cans are being seamed annually and the study of problem related to seaming is very beneficial to the entire beverage industry whether it is alcoholic or non-alcoholic. This type of study helps to minimize the leakage occurring problems from seam area and helps to properly form the double seam with appropriate seaming parameters. Apart from leakages, the improper seam formation may lead to the negative impact such as microbial contamination, gas leakages and minute metal particles mixed in beverages, which are all very serious issues regarding the consumers health. Further research can be conducted on effectiveness of seaming process and problems faced in higher production capacity and more advanced can seamer.

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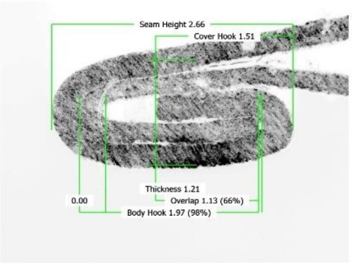
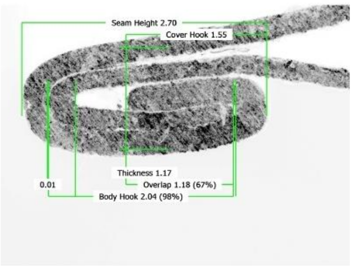
Appendix 1. Seaming parameters of 25 leakage cans from Seam View Machine

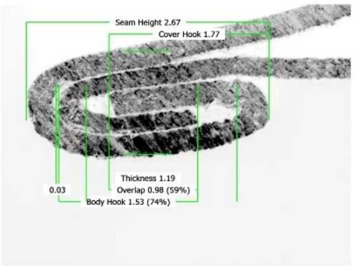
SEAMview 6.0.58: **Double Seam Images** **2023/06/13 15:41**

Test: **2023-06-13--13-56-35--Double Seam** **Page 1 of 7**

	Thicknes mm	Seam Height mm	Gap mm	Cover Hook mm	Body Hook mm	Overlap mm	Overlap % %	Bodyhook Butting %	
1	1.21	2.66	0.00	1.51	1.97	1.13	66	98	H1P1
2	1.17	2.70	0.01	1.55	2.04	1.18	67	98	H1P2
3	1.19	2.67	0.03	1.77	1.53	0.98	59	74	H2P1
4	1.17	2.70	0.03	1.75	1.76	1.16	66	86	H2P2
5	1.16	2.70	0.01	1.80	1.56	0.97	54	73	H3P1
6	1.15	2.70	0.00	1.77	1.70	1.09	63	84	H3P2
7	1.15	2.80	0.01	1.46	2.00	0.94	49	92	H4P1
8	1.20	2.77	0.00	1.41	1.94	0.89	50	92	H4P2
9	1.17	2.69	0.02	1.84	1.73	1.21	68	82	H5P1
10	1.19	2.69	0.00	1.73	1.47	0.84	48	70	H5P2
11	1.18	2.69	0.02	1.80	1.81	1.21	69	87	H6P1
12	1.19	2.71	0.03	1.78	1.51	0.93	57	76	H6P2
13	1.21	2.70	0.00	1.63	1.97	1.22	67	96	H7P1
14	1.19	2.67	0.00	1.53	2.02	1.11	62	96	H7P2
15	1.16	2.64	0.03	1.75	1.71	1.14	68	83	H8P1
16	1.18	2.68	0.03	1.87	1.48	0.98	56	70	H8P2
17	1.25	2.77	0.01	1.56	2.13	1.19	62	99	H9P1
18	1.29	2.72	0.01	1.45	2.11	1.11	59	99	H9P2
19	1.16	2.64	0.01	1.72	1.68	1.09	62	82	H10P1
20	1.18	2.63	0.03	1.73	1.58	1.01	57	76	H10P2
21	1.20	2.66	0.01	1.80	1.63	1.07	61	78	H11P1
22	1.19	2.69	0.08	1.90	1.56	1.13	64	74	H11P2
23	1.17	2.68	0.03	1.72	1.58	0.97	56	77	H12P1
24	1.16	2.71	0.00	1.82	1.77	1.16	64	84	H12P2
25	1.19	2.70	0.04	1.75	1.62	1.02	59	78	H13P1
26	1.21	2.70	0.11	1.74	1.63	1.08	65	79	H13P2
27	1.23	2.65	0.03	1.63	1.96	1.26	71	98	H14P1
28	1.25	2.69	0.01	1.56	1.83	1.00	56	88	H14P2
29	1.19	2.68	0.03	1.82	1.69	1.15	65	82	H15P1
30	1.19	2.64	0.01	1.76	1.56	1.00	59	75	H15P2
31	1.19	2.69	0.04	1.77	1.79	1.19	71	88	H16P1
32	1.19	2.73	0.01	1.76	1.52	0.86	48	69	H16P2
33	1.16	2.72	0.03	1.61	1.84	1.07	65	89	H17P1
34	1.20	2.68	0.01	1.74	1.98	1.36	78	97	H17P2
35	1.19	2.66	0.02	1.80	1.61	1.04	59	76	H18P1
36	1.19	2.73	0.00	1.75	1.79	1.12	63	85	H18P2
37	1.19	2.69	0.12	1.79	1.62	1.15	68	80	H19P1
38	1.19	2.72	0.04	1.77	1.84	1.22	69	88	H19P2
39	1.30	2.71	0.02	1.68	1.74	1.00	57	87	H20P1
40	1.28	2.70	0.01	1.89	1.80	1.27	74	90	H20P2
41	1.20	2.73	0.03	1.90	1.56	1.05	58	72	H21P1
42	1.20	2.71	0.04	1.76	1.63	1.01	56	77	H21P2
43	1.27	2.54	0.01	1.86	1.73	1.31	77	87	H22P1
44	1.33	2.65	0.00	1.86	1.67	1.14	66	82	H22P2
45	1.18	2.68	0.06	1.80	1.45	0.96	55	70	H23P1
46	1.20	2.69	0.02	1.81	1.71	1.14	65	81	H23P2
47	1.20	2.68	0.04	1.46	2.00	1.10	61	99	H24P1
48	1.22	2.68	0.02	1.56	1.80	0.99	57	88	H24P2
49	1.21	2.80	0.03	1.49	2.01	1.02	55	94	H25P1
50	1.24	2.81	0.06	1.35	1.82	0.70	38	84	H25P2
max	1.33	2.81	0.12	1.90	2.13	1.36	78	99	
xbar	1.20	2.69	0.02	1.71	1.75	1.08	61.4	84.2	
min	1.15	2.54	0.00	1.35	1.45	0.70	38	69	
sigma	0.04	0.05	0.03	0.14	0.18	0.13	7.7	8.9	







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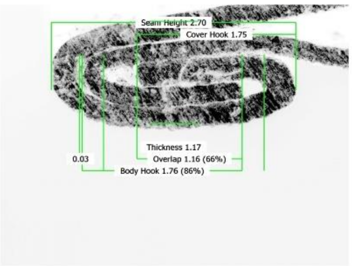

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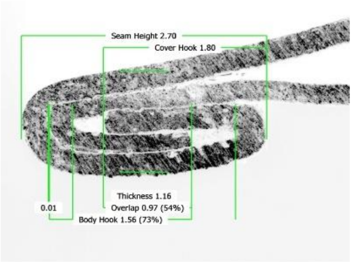

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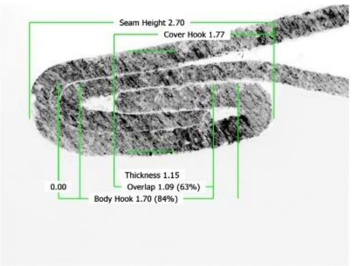

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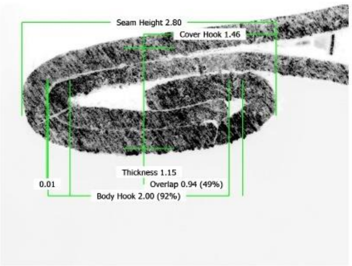

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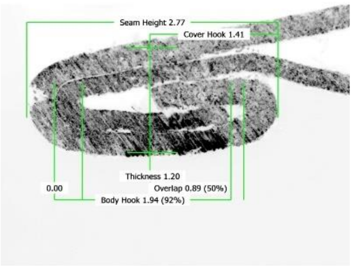

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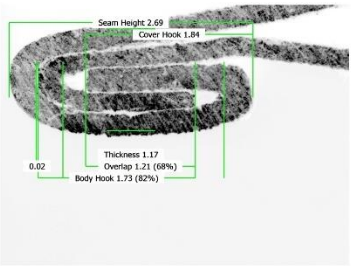

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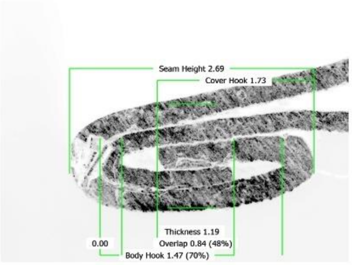

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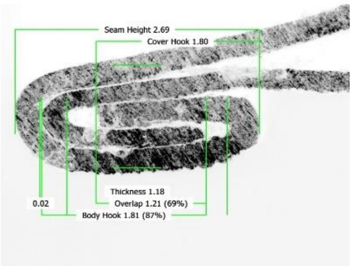

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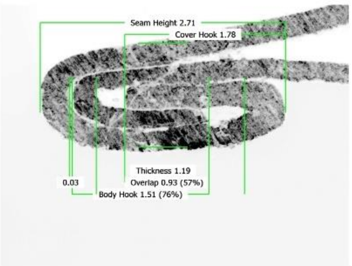

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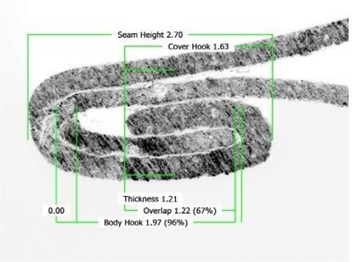

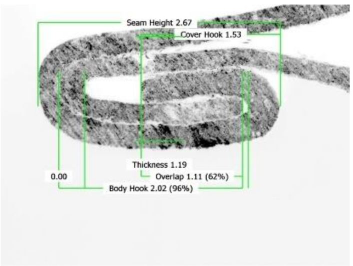

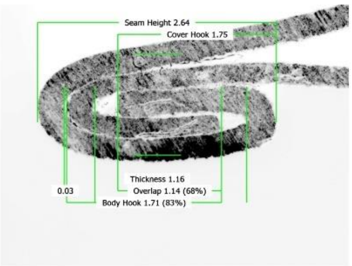

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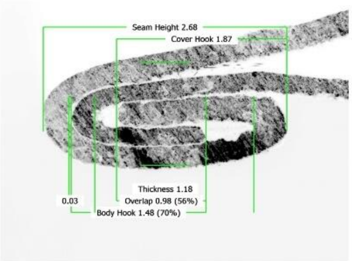

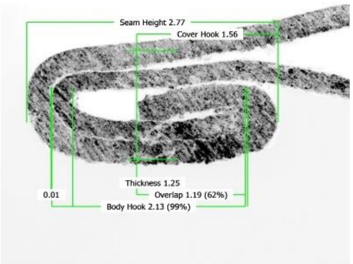

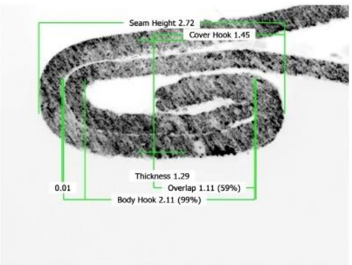

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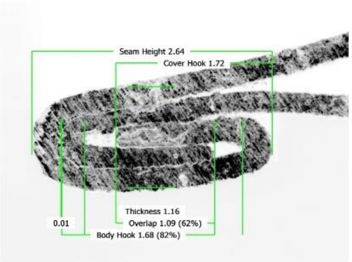

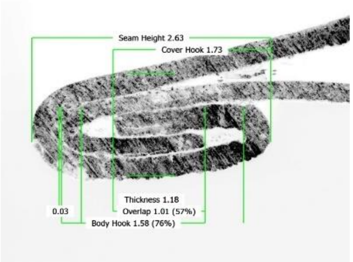

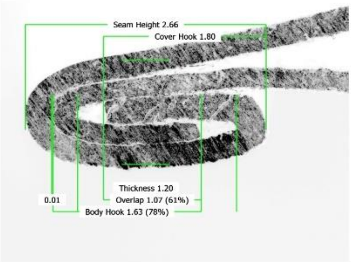

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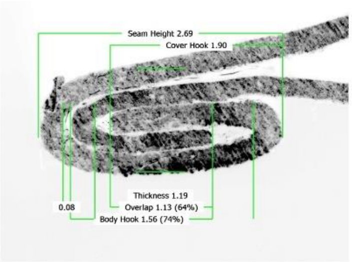
2023-06-13--13-56-35--Double Seam: 20

2023-06-13--13-56-35--Double Seam: 21

SEAMview 6.0.58: **Double Seam Images** **2023/06/13 15:41**

Test: **2023-06-13--13-56-35--Double Seam** **Page 4 of 7**



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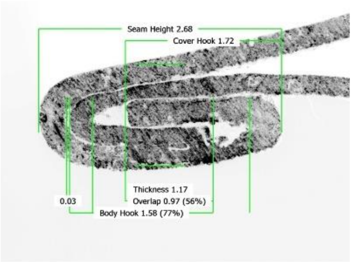

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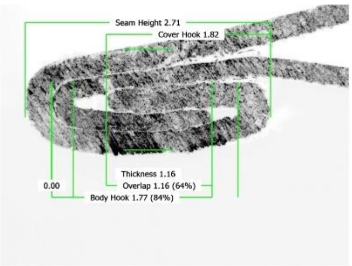

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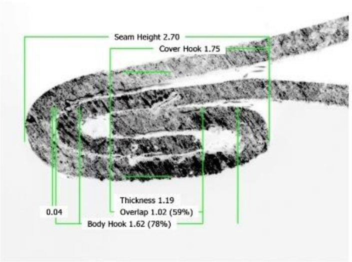

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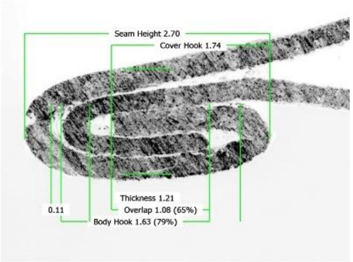

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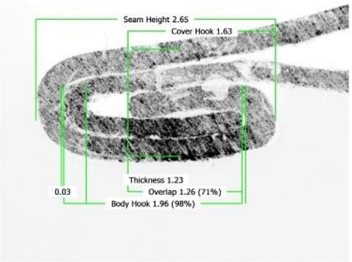

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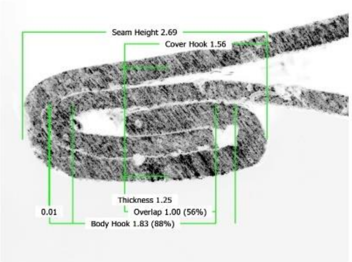

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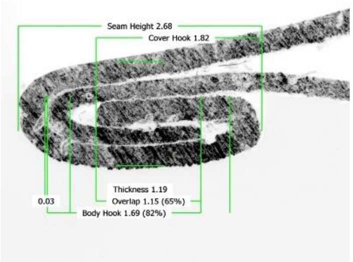

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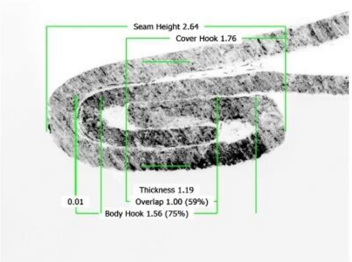

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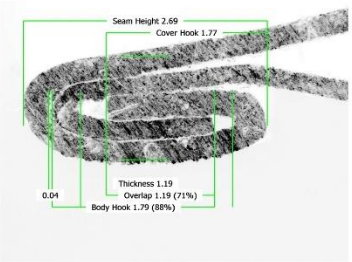

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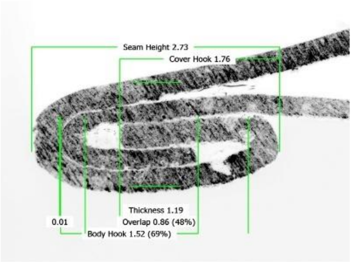

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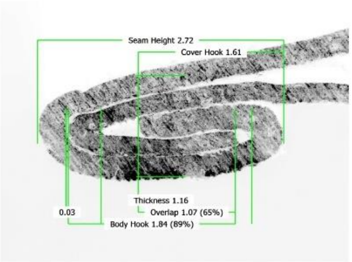

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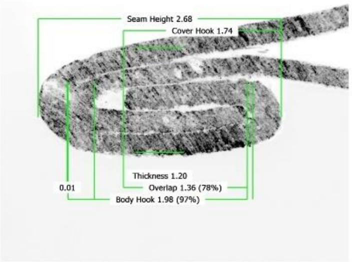

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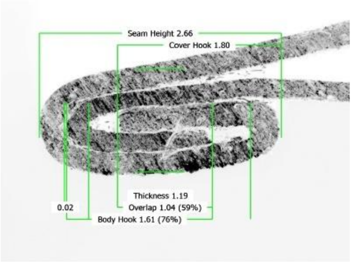

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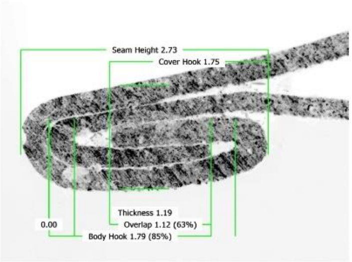

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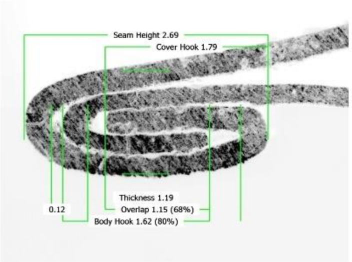

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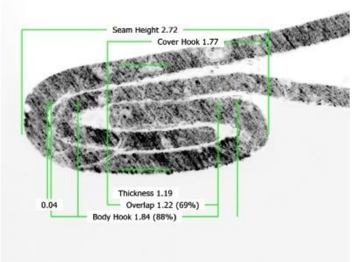

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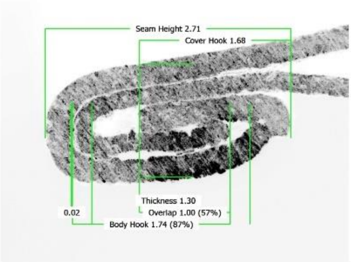

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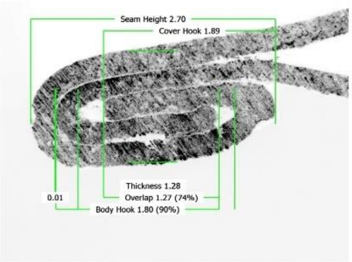

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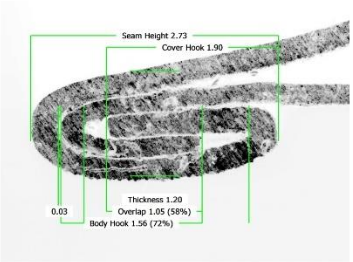

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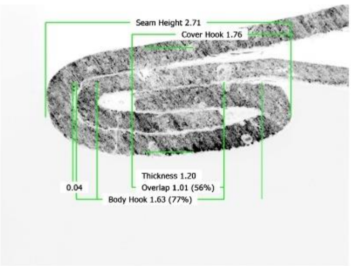

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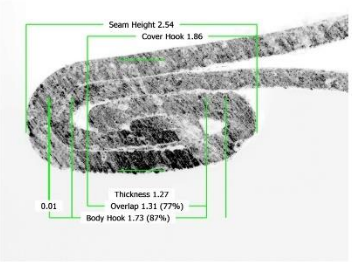

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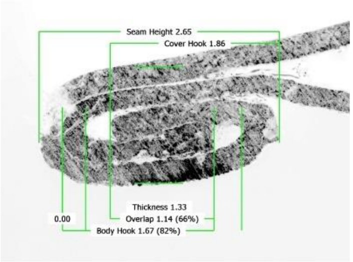

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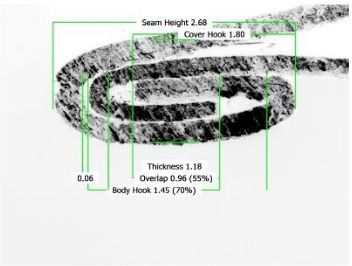

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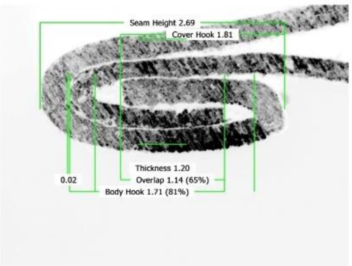

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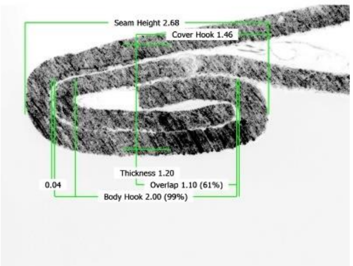

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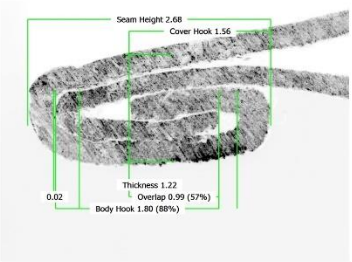
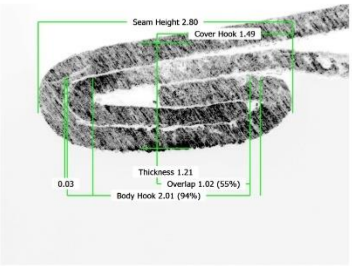


2023-06-13--13-56-35--Double Seam: 48

SEAMview 6.0.58: **Double Seam Images** **2023/06/13 15:41**

Test: **2023-06-13--13-56-35--Double Seam** **Page 7 of 7**



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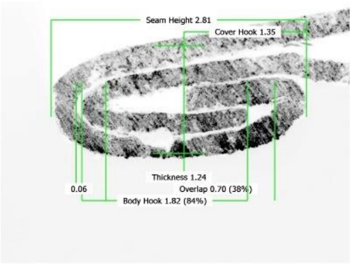
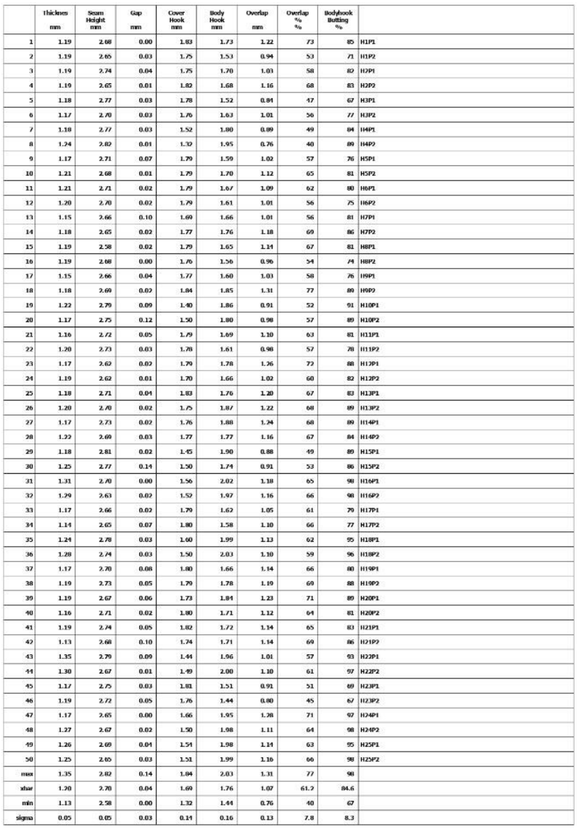


2023-06-13--13-56-35--Double Seam: 50

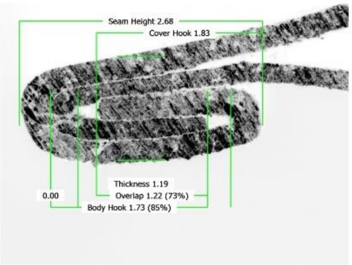
Appendix 2. Seaming parameters of another 25 leakage cans from Seam View Machine

SEAMview 6.0.58: **Double Seam Images** **2023/06/14 16:19**

Test: **2023-06-14--15-48-10--Double Seam** **Page 1 of 7**



	Thicknes mm	Seam Height mm	Gap mm	Cover Hook mm	Body Hook mm	Overlap mm	Overlap % %	Bodyhook Butting %	
1	1.19	2.68	0.00	1.83	1.73	1.22	73	85	H1P1
2	1.19	2.65	0.03	1.75	1.53	0.94	53	71	H1P2
3	1.19	2.74	0.04	1.75	1.70	1.03	58	82	H2P1
4	1.19	2.65	0.01	1.82	1.68	1.16	68	83	H2P2
5	1.18	2.77	0.03	1.78	1.52	0.84	47	67	H3P1
6	1.17	2.70	0.03	1.76	1.63	1.01	56	77	H3P2
7	1.18	2.77	0.03	1.52	1.80	0.89	49	84	H4P1
8	1.24	2.82	0.01	1.32	1.95	0.76	40	89	H4P2
9	1.17	2.71	0.07	1.79	1.59	1.02	57	76	H5P1
10	1.21	2.68	0.01	1.79	1.70	1.12	65	81	H5P2
11	1.21	2.71	0.02	1.79	1.67	1.09	62	80	H6P1
12	1.20	2.70	0.02	1.79	1.61	1.01	56	75	H6P2
13	1.15	2.66	0.10	1.69	1.66	1.01	56	81	H7P1
14	1.18	2.65	0.02	1.77	1.76	1.18	69	86	H7P2
15	1.19	2.58	0.02	1.79	1.65	1.14	67	81	H8P1
16	1.19	2.68	0.00	1.76	1.56	0.96	54	74	H8P2
17	1.15	2.66	0.04	1.77	1.60	1.03	58	76	H9P1
18	1.18	2.69	0.02	1.84	1.85	1.31	77	89	H9P2
19	1.22	2.79	0.09	1.40	1.86	0.91	52	91	H10P1
20	1.17	2.75	0.12	1.50	1.80	0.98	57	89	H10P2
21	1.16	2.72	0.05	1.79	1.69	1.10	63	81	H11P1
22	1.20	2.73	0.03	1.78	1.61	0.98	57	78	H11P2
23	1.17	2.62	0.02	1.79	1.78	1.26	72	88	H12P1
24	1.19	2.62	0.01	1.70	1.66	1.02	60	82	H12P2
25	1.18	2.71	0.04	1.83	1.76	1.20	67	83	H13P1
26	1.20	2.70	0.02	1.75	1.87	1.22	68	89	H13P2
27	1.17	2.73	0.02	1.76	1.88	1.24	68	89	H14P1
28	1.22	2.69	0.03	1.77	1.77	1.16	67	84	H14P2
29	1.18	2.81	0.02	1.45	1.90	0.88	49	89	H15P1
30	1.25	2.77	0.14	1.50	1.74	0.91	53	86	H15P2
31	1.31	2.70	0.00	1.56	2.02	1.18	65	98	H16P1
32	1.29	2.63	0.02	1.52	1.97	1.16	66	98	H16P2
33	1.17	2.66	0.02	1.79	1.62	1.05	61	79	H17P1
34	1.14	2.65	0.07	1.80	1.58	1.10	66	77	H17P2
35	1.24	2.78	0.03	1.60	1.99	1.13	62	95	H18P1
36	1.28	2.74	0.03	1.50	2.03	1.10	59	96	H18P2
37	1.17	2.70	0.08	1.80	1.66	1.14	66	80	H19P1
38	1.19	2.73	0.05	1.79	1.78	1.19	69	88	H19P2
39	1.19	2.67	0.06	1.73	1.84	1.23	71	89	H20P1
40	1.16	2.71	0.02	1.80	1.71	1.12	64	81	H20P2
41	1.19	2.74	0.05	1.82	1.72	1.14	65	83	H21P1
42	1.13	2.68	0.10	1.74	1.71	1.14	69	86	H21P2
43	1.35	2.79	0.09	1.44	1.96	1.01	57	93	H22P1
44	1.30	2.67	0.01	1.49	2.00	1.10	61	97	H22P2
45	1.17	2.75	0.03	1.81	1.51	0.91	51	69	H23P1
46	1.19	2.72	0.05	1.76	1.44	0.80	45	67	H23P2
47	1.17	2.65	0.00	1.66	1.95	1.28	71	97	H24P1
48	1.27	2.67	0.02	1.50	1.98	1.11	64	98	H24P2
49	1.26	2.69	0.04	1.54	1.98	1.14	63	95	H25P1
50	1.25	2.65	0.03	1.51	1.99	1.16	66	98	H25P2
max	1.35	2.82	0.14	1.84	2.03	1.31	77	98	
xbar	1.20	2.70	0.04	1.69	1.76	1.07	61.2	84.6	
min	1.13	2.58	0.00	1.32	1.44	0.76	40	67	
sigma	0.05	0.05	0.03	0.14	0.16	0.13	7.8	8.3	



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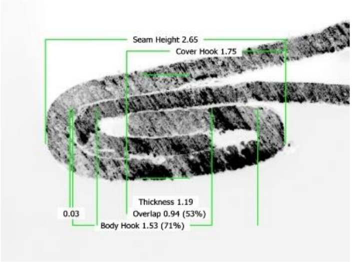

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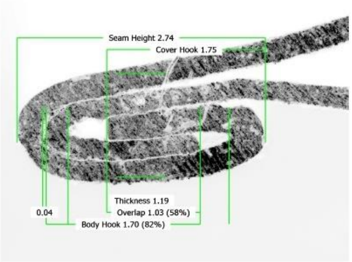

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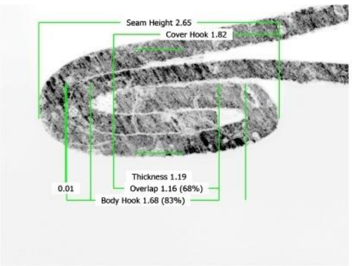
SEAMview 6.0.58: **Double Seam Images** **2023/06/14 16:19**

Test: **2023-06-14--15-48-10--Double Seam** **Page 2 of 7**



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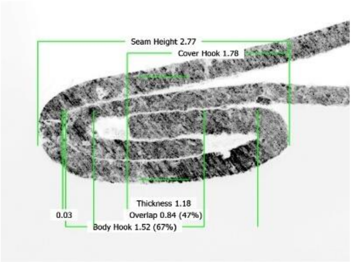

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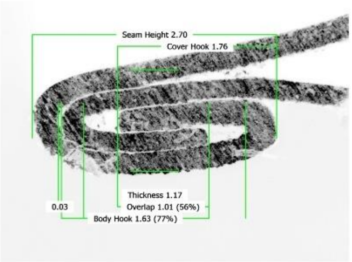

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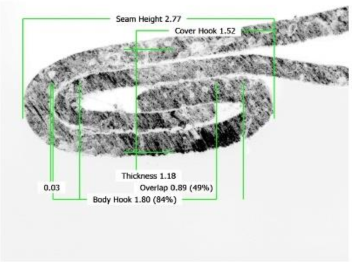

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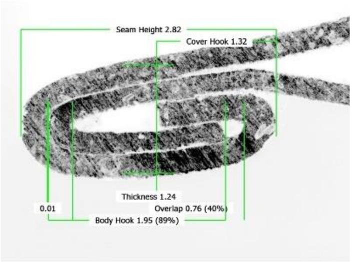

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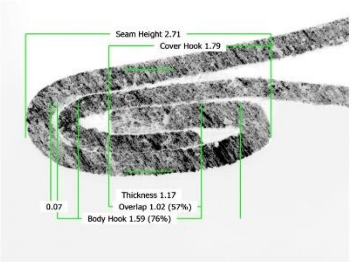

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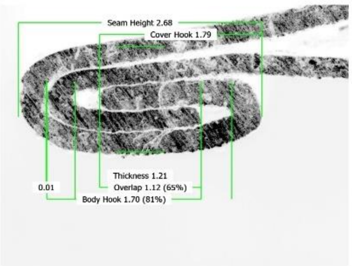

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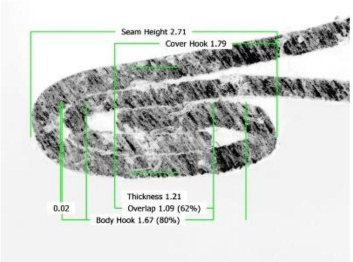

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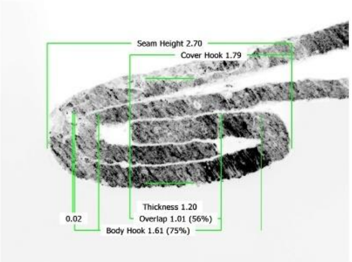

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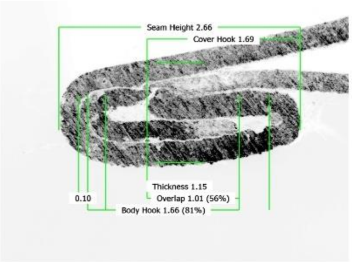

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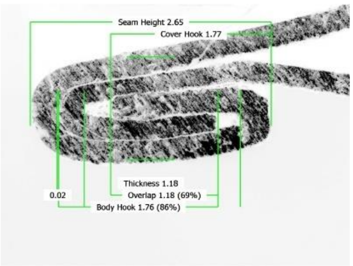

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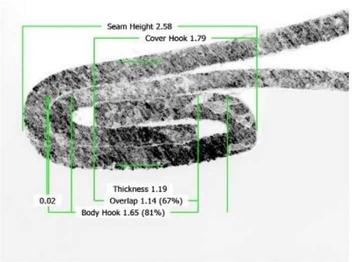

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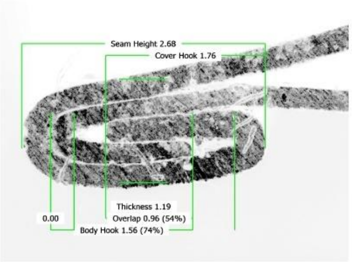

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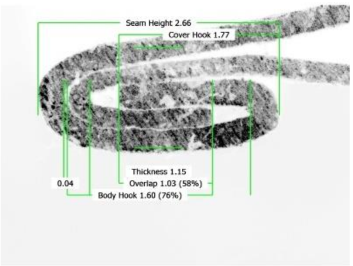

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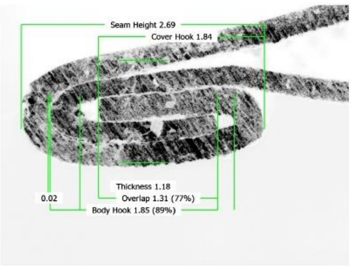

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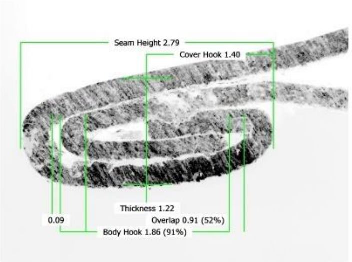

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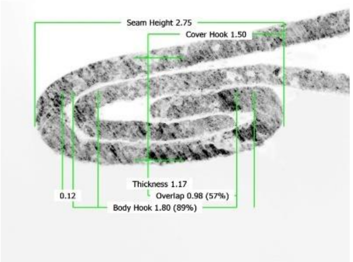

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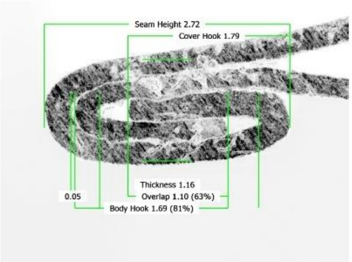

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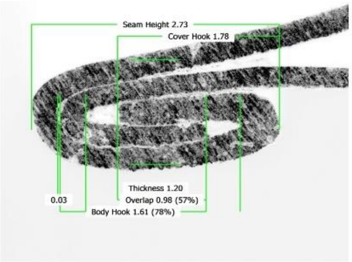

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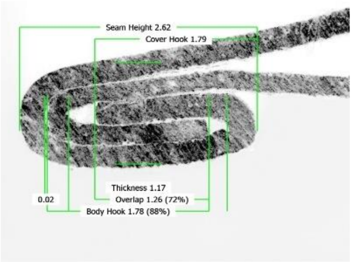

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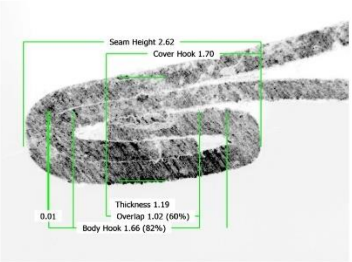

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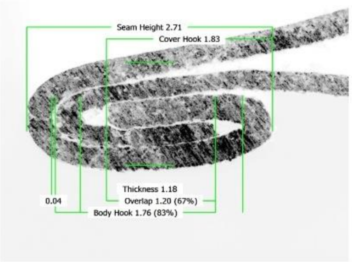

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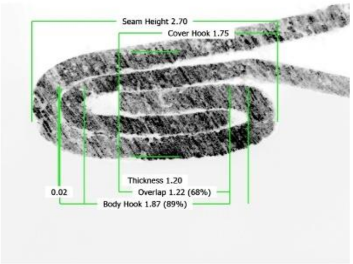

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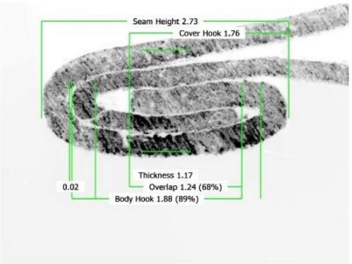

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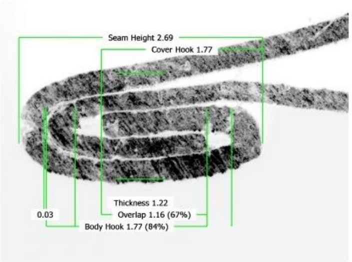

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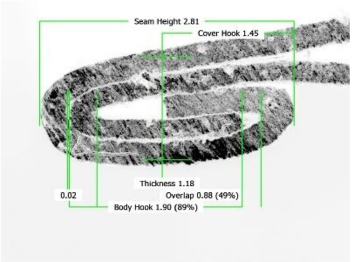

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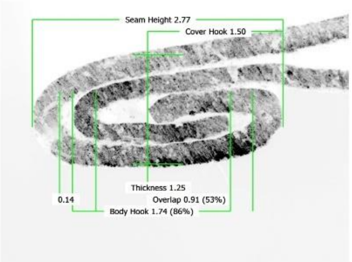

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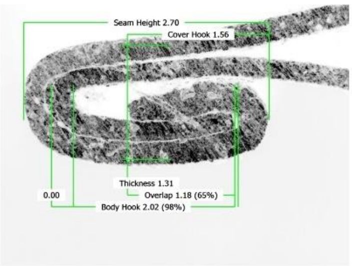

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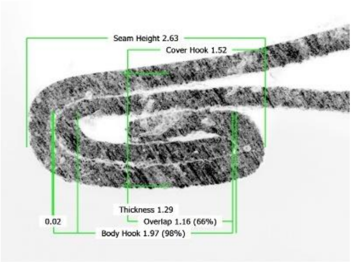

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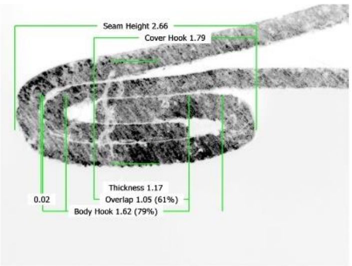

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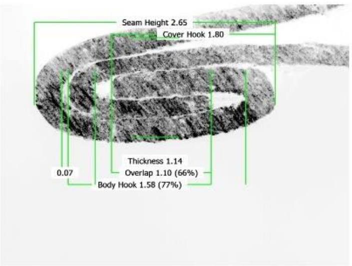

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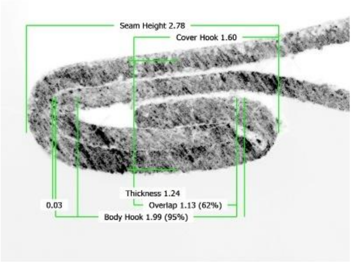

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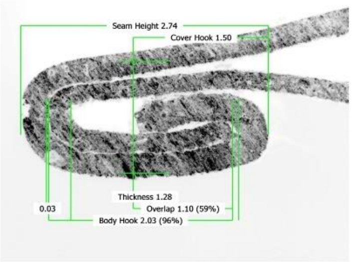

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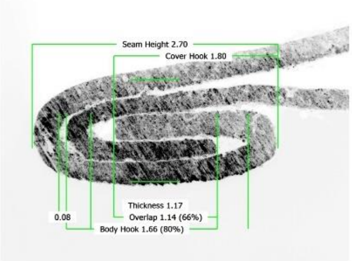

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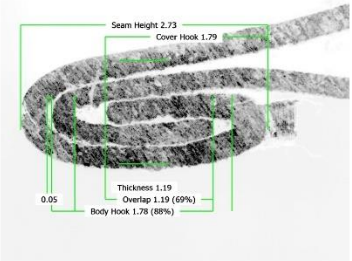

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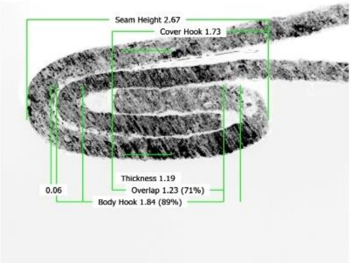

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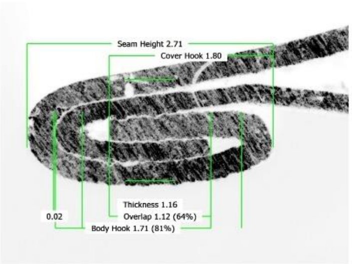

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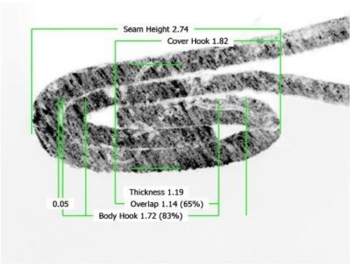

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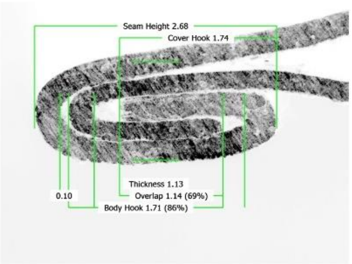

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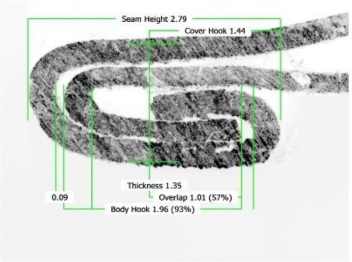

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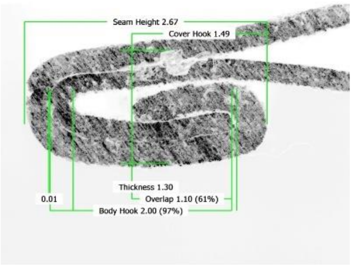

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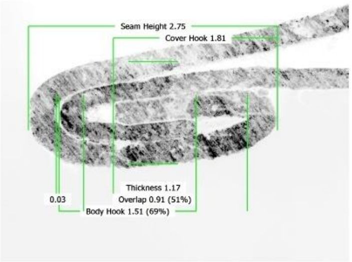

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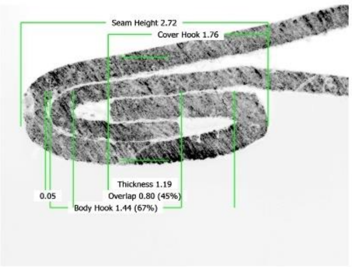

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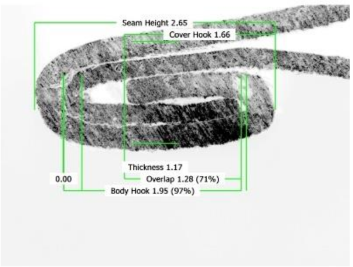

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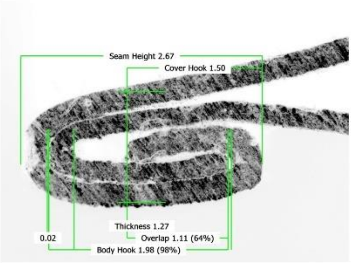

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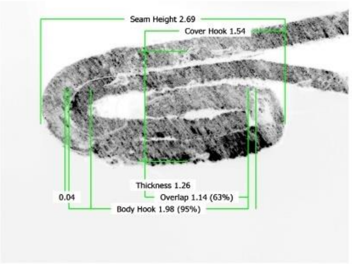
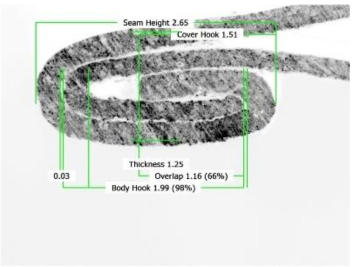
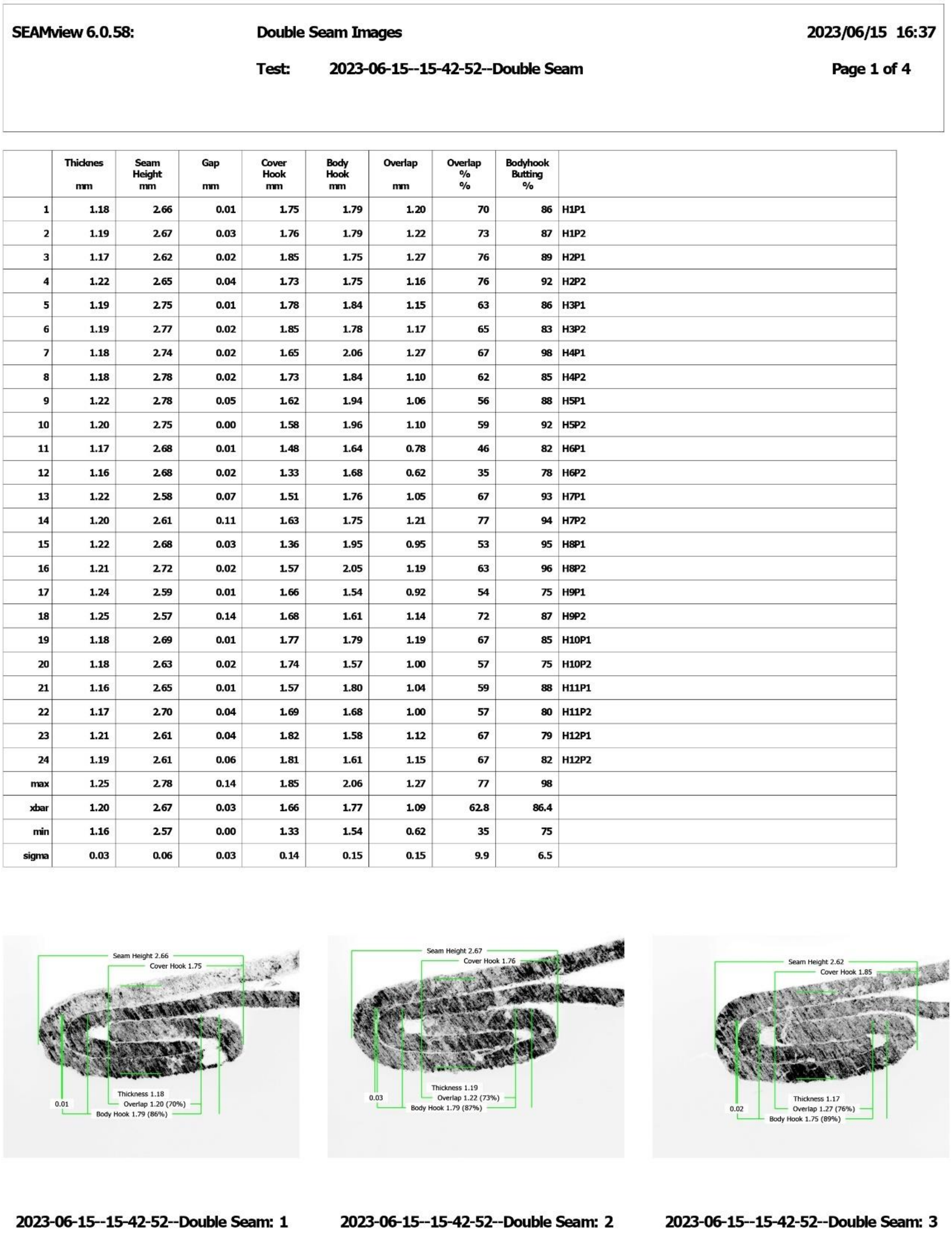




2023-06-14--15-48-10--Double Seam: 49

2023-06-14--15-48-10--Double Seam: 50

Appendix 3. Seaming parameters of 12 non-leakage cans from Seam View Machine



SEAMview 6.0.58: **Double Seam Images** **2023/06/15 16:37**

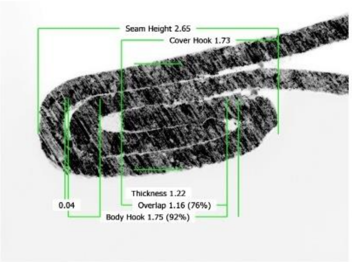
Test: **2023-06-15--15-42-52--Double Seam** **Page 1 of 4**

	Thicknes mm	Seam Height mm	Gap mm	Cover Hook mm	Body Hook mm	Overlap mm	Overlap % %	Bodyhook Butting %	
1	1.18	2.66	0.01	1.75	1.79	1.20	70	86	H1P1
2	1.19	2.67	0.03	1.76	1.79	1.22	73	87	H1P2
3	1.17	2.62	0.02	1.85	1.75	1.27	76	89	H2P1
4	1.22	2.65	0.04	1.73	1.75	1.16	76	92	H2P2
5	1.19	2.75	0.01	1.78	1.84	1.15	63	86	H3P1
6	1.19	2.77	0.02	1.85	1.78	1.17	65	83	H3P2
7	1.18	2.74	0.02	1.65	2.06	1.27	67	98	H4P1
8	1.18	2.78	0.02	1.73	1.84	1.10	62	85	H4P2
9	1.22	2.78	0.05	1.62	1.94	1.06	56	88	H5P1
10	1.20	2.75	0.00	1.58	1.96	1.10	59	92	H5P2
11	1.17	2.68	0.01	1.48	1.64	0.78	46	82	H6P1
12	1.16	2.68	0.02	1.33	1.68	0.62	35	78	H6P2
13	1.22	2.58	0.07	1.51	1.76	1.05	67	93	H7P1
14	1.20	2.61	0.11	1.63	1.75	1.21	77	94	H7P2
15	1.22	2.68	0.03	1.36	1.95	0.95	53	95	H8P1
16	1.21	2.72	0.02	1.57	2.05	1.19	63	96	H8P2
17	1.24	2.59	0.01	1.66	1.54	0.92	54	75	H9P1
18	1.25	2.57	0.14	1.68	1.61	1.14	72	87	H9P2
19	1.18	2.69	0.01	1.77	1.79	1.19	67	85	H10P1
20	1.18	2.63	0.02	1.74	1.57	1.00	57	75	H10P2
21	1.16	2.65	0.01	1.57	1.80	1.04	59	88	H11P1
22	1.17	2.70	0.04	1.69	1.68	1.00	57	80	H11P2
23	1.21	2.61	0.04	1.82	1.58	1.12	67	79	H12P1
24	1.19	2.61	0.06	1.81	1.61	1.15	67	82	H12P2
max	1.25	2.78	0.14	1.85	2.06	1.27	77	98	
xbar	1.20	2.67	0.03	1.66	1.77	1.09	62.8	86.4	
min	1.16	2.57	0.00	1.33	1.54	0.62	35	75	
sigma	0.03	0.06	0.03	0.14	0.15	0.15	9.9	6.5	

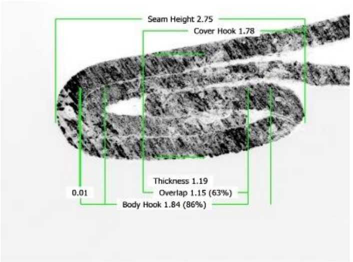
2023-06-15--15-42-52--Double Seam: 1 **2023-06-15--15-42-52--Double Seam: 2** **2023-06-15--15-42-52--Double Seam: 3**

SEAMview 6.0.58: **Double Seam Images** **2023/06/15 16:37**

Test: **2023-06-15--15-42-52--Double Seam** **Page 2 of 4**



2023-06-15--15-42-52--Double Seam: 4



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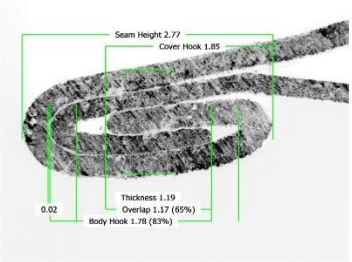

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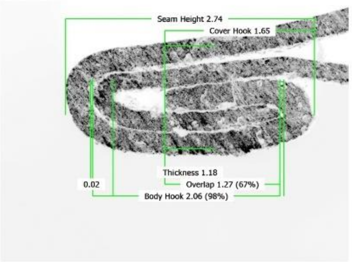

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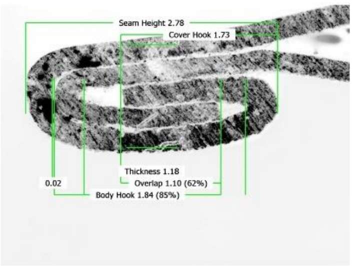

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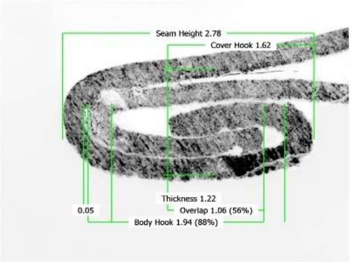

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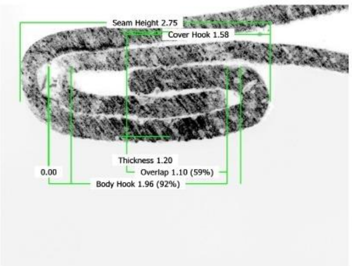

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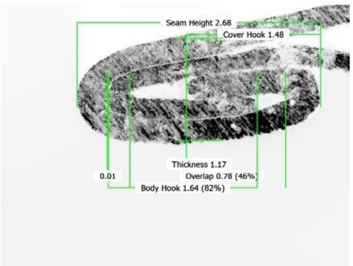

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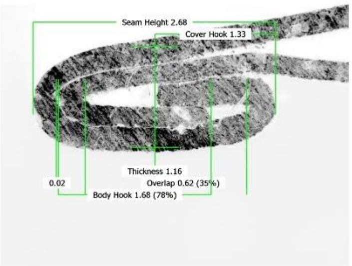
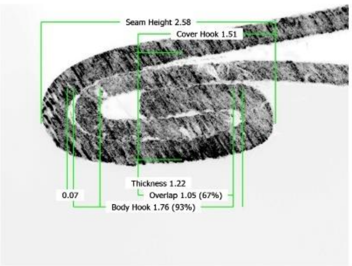


2023-06-15--15-42-52--Double Seam: 12

SEAMview 6.0.58: **Double Seam Images** **2023/06/15 16:37**

Test: **2023-06-15--15-42-52--Double Seam** **Page 3 of 4**



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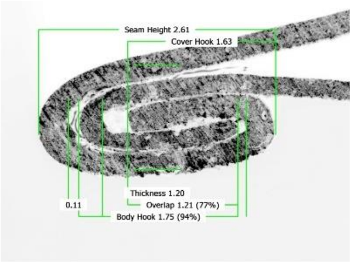

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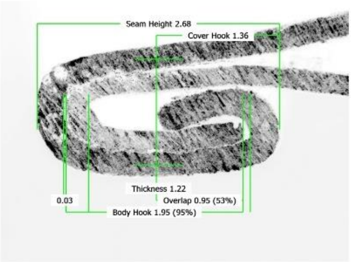

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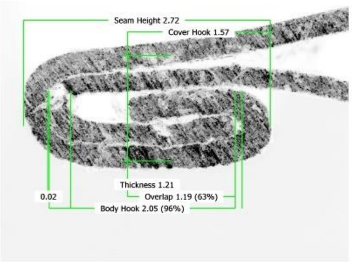

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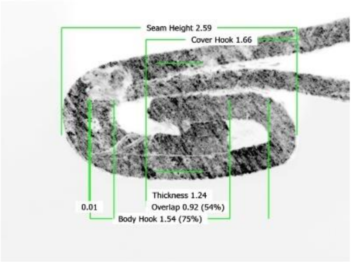

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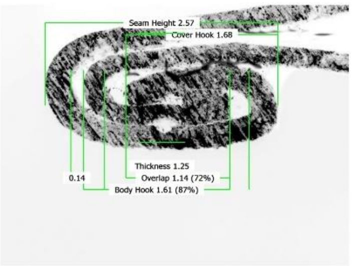

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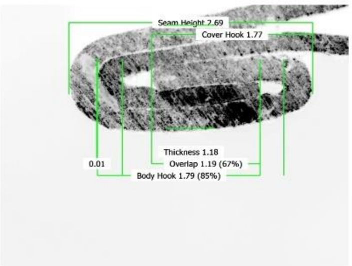

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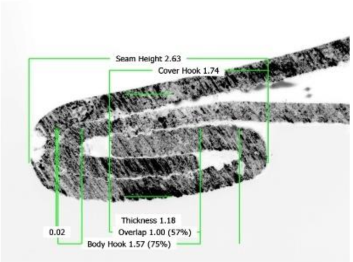

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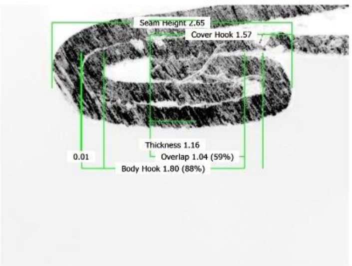

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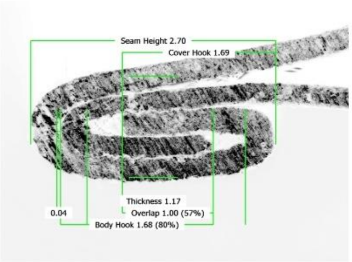
SEAMview 6.0.58: **Double Seam Images** **2023/06/15 16:37**

Test: **2023-06-15--15-42-52--Double Seam** **Page 4 of 4**



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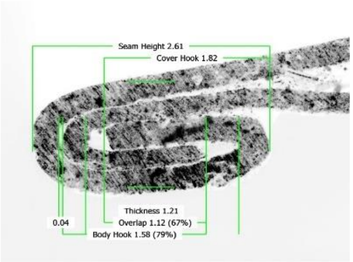

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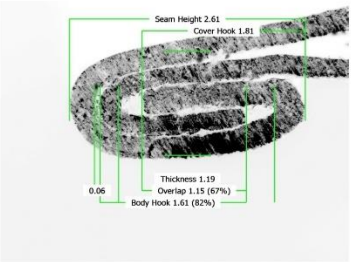
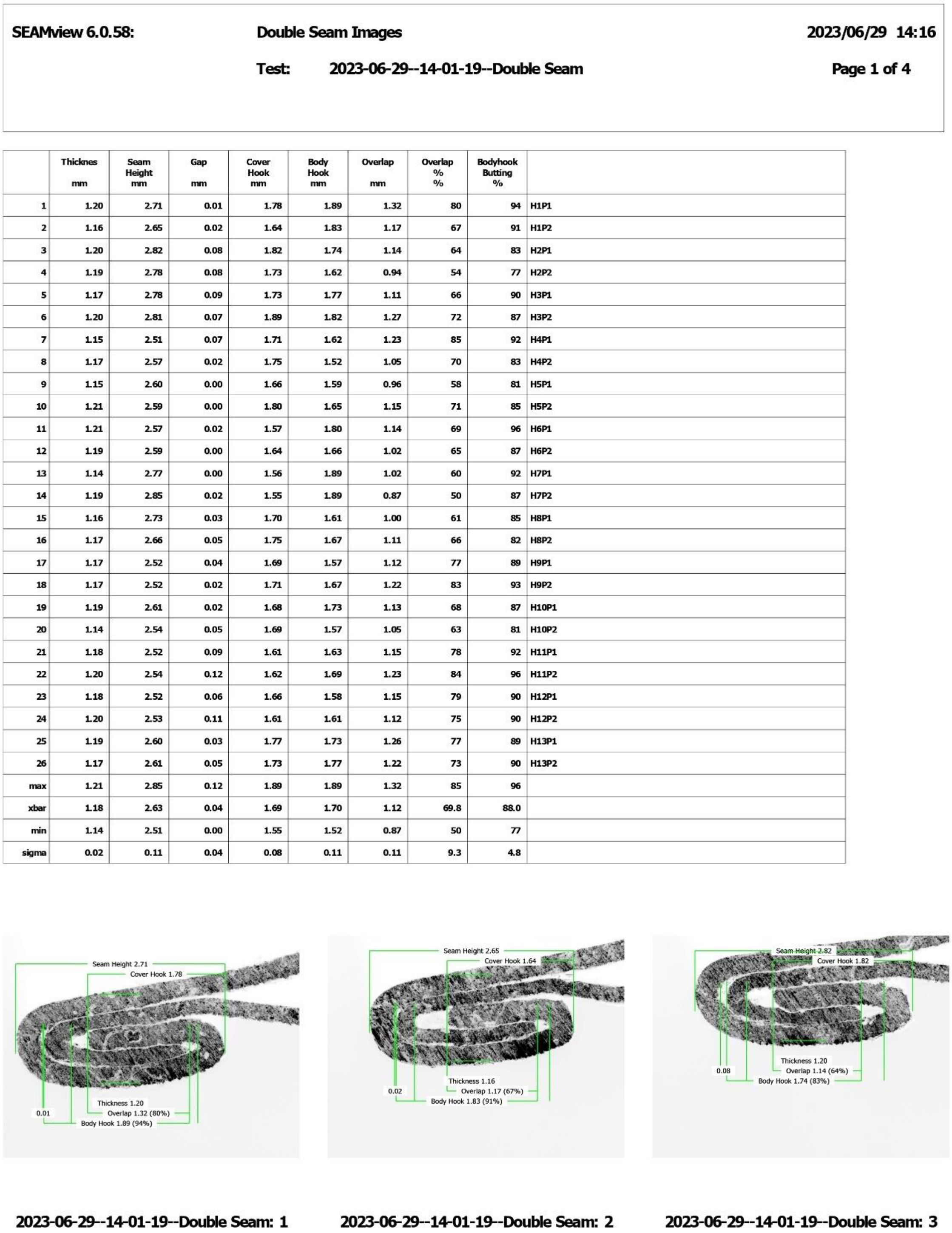


2023-06-15--15-42-52--Double Seam: 24

Appendix 4. Seaming parameters of 13 non-leakage cans from Seam View Machine

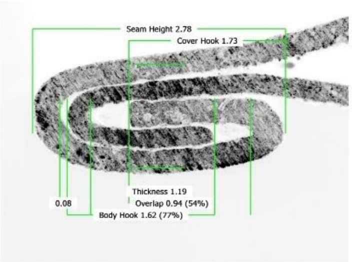


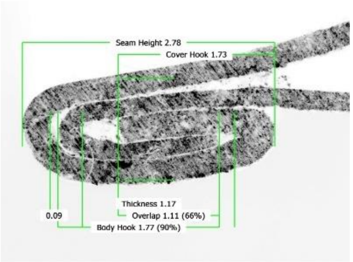
SEAMview 6.0.58: **Double Seam Images** **2023/06/29 14:16**

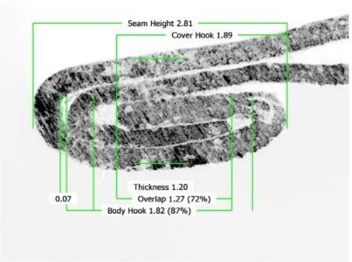
Test: **2023-06-29--14-01-19--Double Seam** **Page 1 of 4**

	Thicknes mm	Seam Height mm	Gap mm	Cover Hook mm	Body Hook mm	Overlap mm	Overlap % %	Bodyhook Butting %	
1	1.20	2.71	0.01	1.78	1.89	1.32	80	94	H1P1
2	1.16	2.65	0.02	1.64	1.83	1.17	67	91	H1P2
3	1.20	2.82	0.08	1.82	1.74	1.14	64	83	H2P1
4	1.19	2.78	0.08	1.73	1.62	0.94	54	77	H2P2
5	1.17	2.78	0.09	1.73	1.77	1.11	66	90	H3P1
6	1.20	2.81	0.07	1.89	1.82	1.27	72	87	H3P2
7	1.15	2.51	0.07	1.71	1.62	1.23	85	92	H4P1
8	1.17	2.57	0.02	1.75	1.52	1.05	70	83	H4P2
9	1.15	2.60	0.00	1.66	1.59	0.96	58	81	H5P1
10	1.21	2.59	0.00	1.80	1.65	1.15	71	85	H5P2
11	1.21	2.57	0.02	1.57	1.80	1.14	69	96	H6P1
12	1.19	2.59	0.00	1.64	1.66	1.02	65	87	H6P2
13	1.14	2.77	0.00	1.56	1.89	1.02	60	92	H7P1
14	1.19	2.85	0.02	1.55	1.89	0.87	50	87	H7P2
15	1.16	2.73	0.03	1.70	1.61	1.00	61	85	H8P1
16	1.17	2.66	0.05	1.75	1.67	1.11	66	82	H8P2
17	1.17	2.52	0.04	1.69	1.57	1.12	77	89	H9P1
18	1.17	2.52	0.02	1.71	1.67	1.22	83	93	H9P2
19	1.19	2.61	0.02	1.68	1.73	1.13	68	87	H10P1
20	1.14	2.54	0.05	1.69	1.57	1.05	63	81	H10P2
21	1.18	2.52	0.09	1.61	1.63	1.15	78	92	H11P1
22	1.20	2.54	0.12	1.62	1.69	1.23	84	96	H11P2
23	1.18	2.52	0.06	1.66	1.58	1.15	79	90	H12P1
24	1.20	2.53	0.11	1.61	1.61	1.12	75	90	H12P2
25	1.19	2.60	0.03	1.77	1.73	1.26	77	89	H13P1
26	1.17	2.61	0.05	1.73	1.77	1.22	73	90	H13P2
max	1.21	2.85	0.12	1.89	1.89	1.32	85	96	
xbar	1.18	2.63	0.04	1.69	1.70	1.12	69.8	88.0	
min	1.14	2.51	0.00	1.55	1.52	0.87	50	77	
sigma	0.02	0.11	0.04	0.08	0.11	0.11	9.3	4.8	

2023-06-29--14-01-19--Double Seam: 1 **2023-06-29--14-01-19--Double Seam: 2** **2023-06-29--14-01-19--Double Seam: 3**







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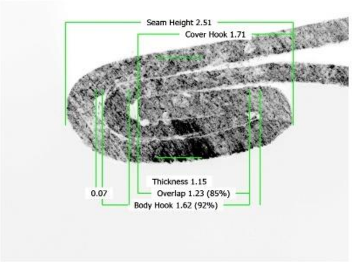
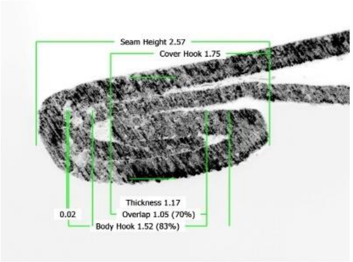
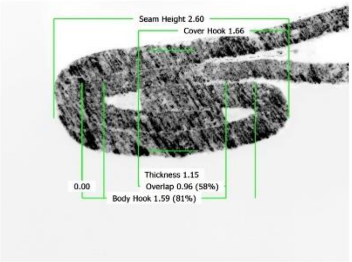
2023-06-29--14-01-19--Double Seam: 5

2023-06-29--14-01-19--Double Seam: 6







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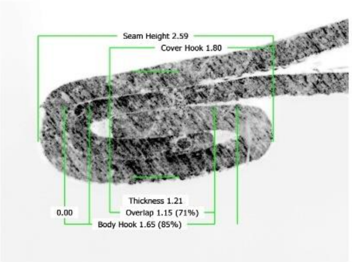
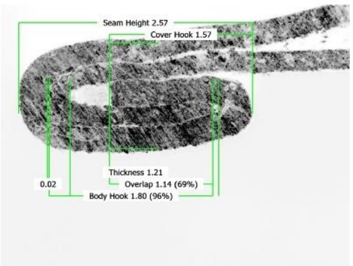
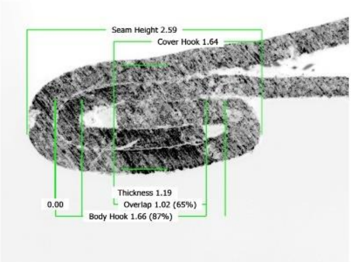
2023-06-29--14-01-19--Double Seam: 8

2023-06-29--14-01-19--Double Seam: 9







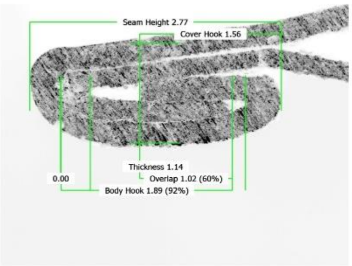
2023-06-29--14-01-19--Double Seam: 10

2023-06-29--14-01-19--Double Seam: 11

2023-06-29--14-01-19--Double Seam: 12

SEAMview 6.0.58: **Double Seam Images** **2023/06/29 14:16**

Test: **2023-06-29--14-01-19--Double Seam** **Page 3 of 4**



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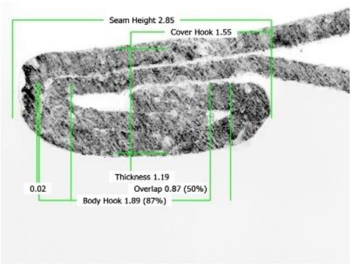

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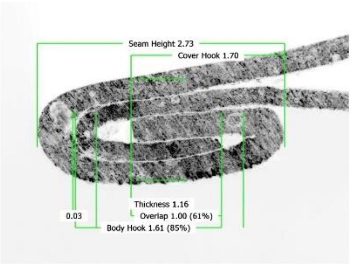

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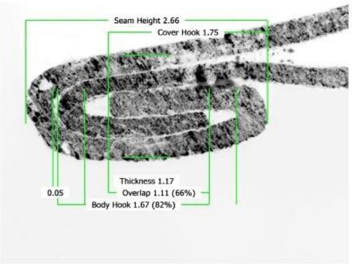

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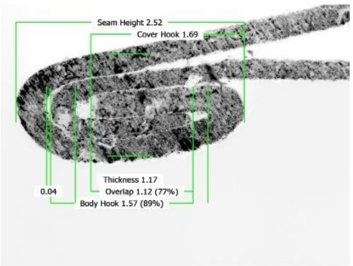

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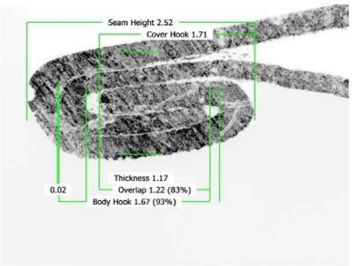

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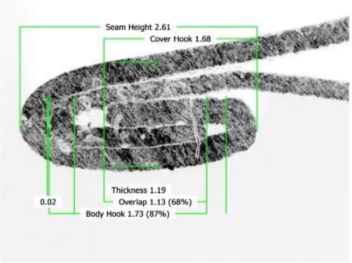

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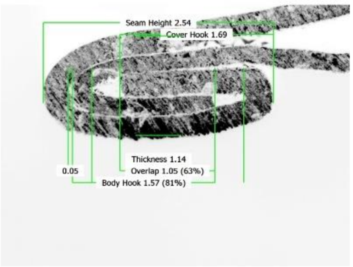

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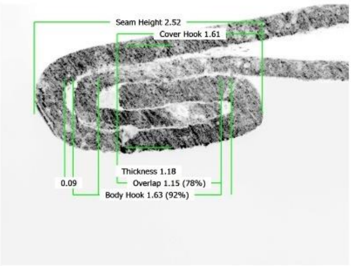

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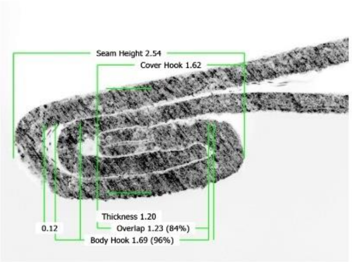

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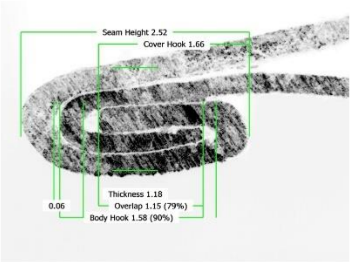

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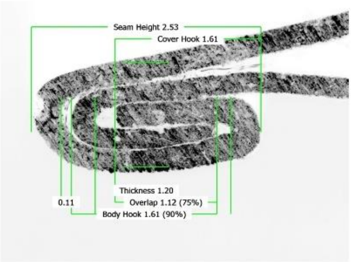

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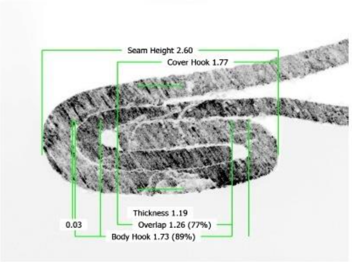

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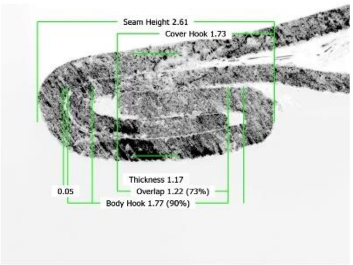


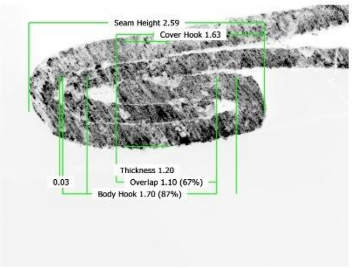
2023-06-29--14-01-19--Double Seam: 26

Appendix 5. Seaming parameters of 12 non-leakage cans from Seam View Machine

SEAMview 6.0.58: **Double Seam Images** **2023/07/02 15:23**

Test: **2023-07-02--13-48-28--Double Seam** **Page 1 of 4**

	Thicknes mm	Seam Height mm	Gap mm	Cover Hook mm	Body Hook mm	Overlap mm	Overlap % %	Bodyhook Butting %	
1	1.20	2.59	0.03	1.63	1.70	1.10	67	87	H1P1
2	1.21	2.62	0.08	1.43	1.68	0.88	53	86	H1P2
3	1.20	2.68	0.03	1.70	1.62	1.00	58	80	H2P1
4	1.18	2.68	0.05	1.81	1.70	1.22	73	85	H2P2
5	1.21	2.70	0.09	1.61	1.79	1.07	63	89	H3P1
6	1.26	2.75	0.17	1.51	1.75	0.96	57	89	H3P2
7	1.24	2.72	0.05	1.50	1.81	1.00	57	90	H4P1
8	1.24	2.58	0.10	1.49	1.76	1.09	70	95	H4P2
9	1.20	2.61	0.02	1.69	1.78	1.16	70	89	H5P1
10	1.19	2.52	0.04	1.63	1.73	1.14	71	90	H5P2
11	1.17	2.70	0.00	1.60	1.74	0.99	57	84	H6P1
12	1.15	2.69	0.03	1.62	1.73	0.99	57	82	H6P2
13	1.19	2.74	0.04	1.67	1.67	0.96	54	78	H7P1
14	1.21	2.72	0.05	1.66	1.67	0.96	55	79	H7P2
15	1.20	2.51	0.06	1.68	1.68	1.20	82	95	H8P1
16	1.19	2.54	0.07	1.75	1.62	1.19	80	91	H8P2
17	1.18	2.57	0.06	1.66	1.62	1.06	68	85	H9P1
18	1.20	2.57	0.06	1.77	1.75	1.31	83	95	H9P2
19	1.26	2.55	0.01	1.76	1.78	1.33	85	97	H10P1
20	1.20	2.49	0.00	1.69	1.78	1.28	83	98	H10P2
21	1.15	2.66	0.06	1.60	1.86	1.15	66	92	H11P1
22	1.17	2.65	0.06	1.76	1.72	1.18	70	86	H11P2
23	1.17	2.63	0.00	1.77	1.77	1.21	70	86	H12P1
24	1.19	2.67	0.00	1.77	1.64	1.03	58	79	H12P2
max	1.26	2.75	0.17	1.81	1.86	1.33	85	98	
xbar	1.20	2.63	0.05	1.66	1.72	1.10	67.0	87.7	
min	1.15	2.49	0.00	1.43	1.62	0.88	53	78	
sigma	0.03	0.08	0.04	0.10	0.06	0.12	10.1	5.8	



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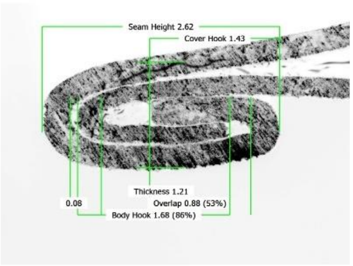

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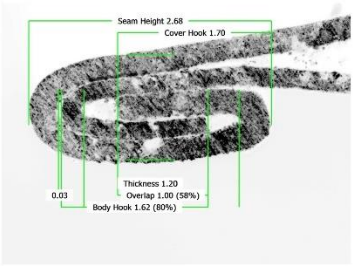

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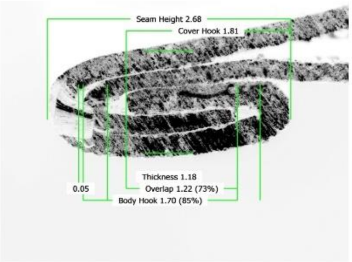

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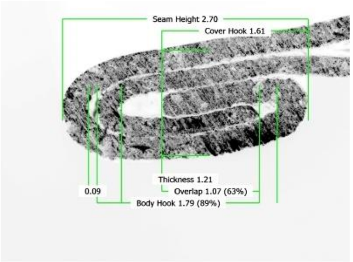

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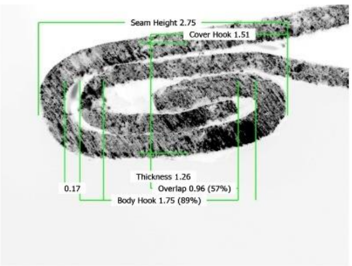

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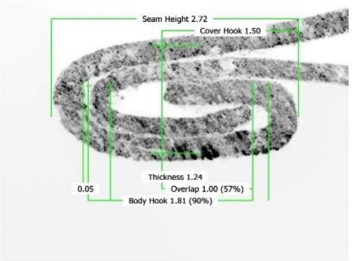

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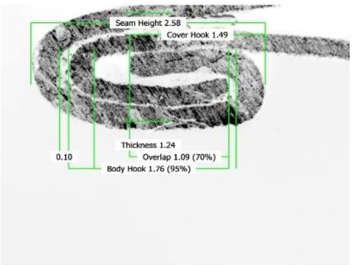

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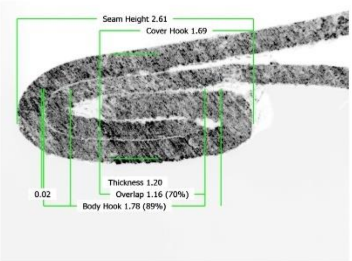

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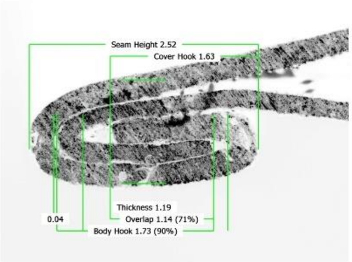

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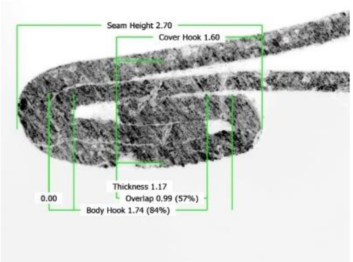

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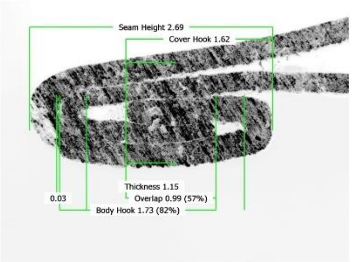
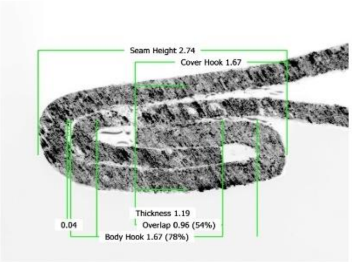


2023-07-02--13-48-28--Double Seam: 12

SEAMview 6.0.58: **Double Seam Images** **2023/07/02 15:23**

Test: **2023-07-02--13-48-28--Double Seam** **Page 3 of 4**



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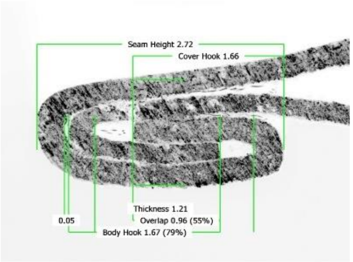

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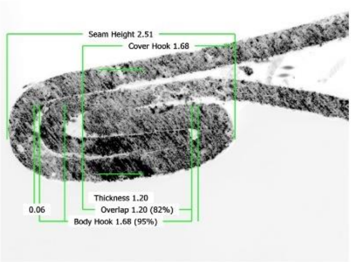

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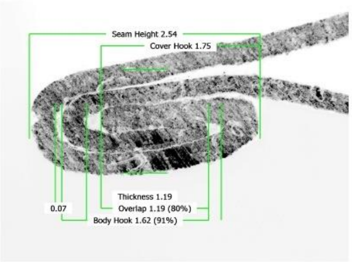

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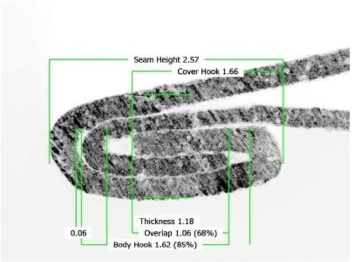

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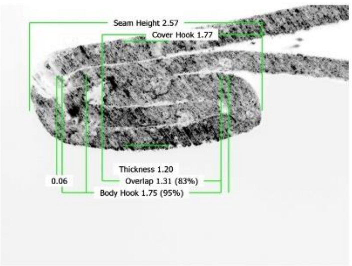

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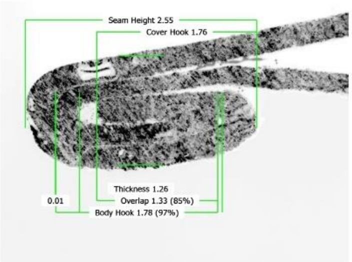

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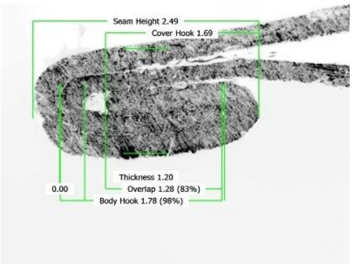

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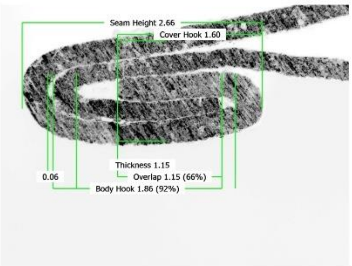

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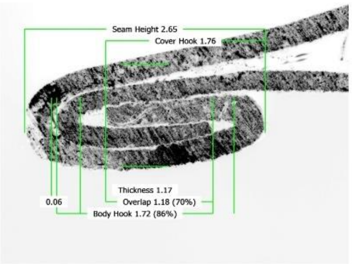

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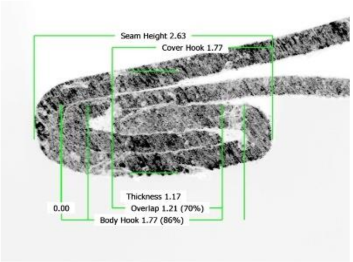

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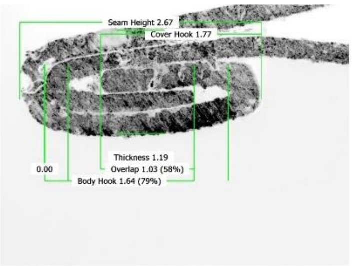
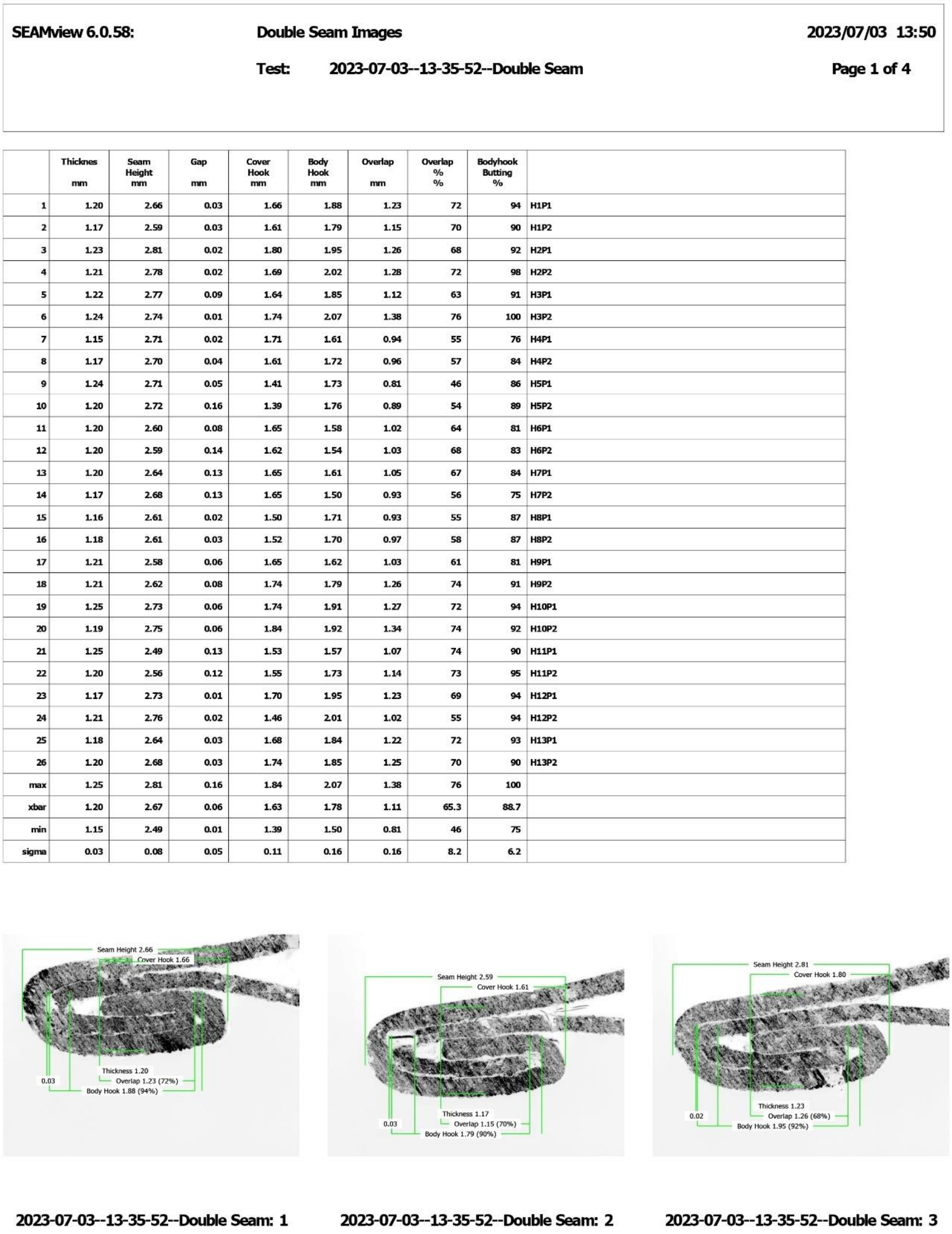


2023-07-02--13-48-28--Double Seam: 24

Appendix 6. Seaming parameters of 13 non-leakage cans from Seam View Machine

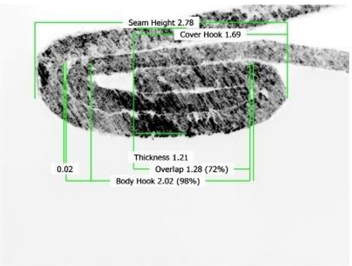


SEAMview 6.0.58: **Double Seam Images** **2023/07/03 13:50**

Test: **2023-07-03--13-35-52--Double Seam** **Page 1 of 4**

	Thicknes mm	Seam Height mm	Gap mm	Cover Hook mm	Body Hook mm	Overlap mm	Overlap % %	Bodyhook Butting %	
1	1.20	2.66	0.03	1.66	1.88	1.23	72	94	H1P1
2	1.17	2.59	0.03	1.61	1.79	1.15	70	90	H1P2
3	1.23	2.81	0.02	1.80	1.95	1.26	68	92	H2P1
4	1.21	2.78	0.02	1.69	2.02	1.28	72	98	H2P2
5	1.22	2.77	0.09	1.64	1.85	1.12	63	91	H3P1
6	1.24	2.74	0.01	1.74	2.07	1.38	76	100	H3P2
7	1.15	2.71	0.02	1.71	1.61	0.94	55	76	H4P1
8	1.17	2.70	0.04	1.61	1.72	0.96	57	84	H4P2
9	1.24	2.71	0.05	1.41	1.73	0.81	46	86	H5P1
10	1.20	2.72	0.16	1.39	1.76	0.89	54	89	H5P2
11	1.20	2.60	0.08	1.65	1.58	1.02	64	81	H6P1
12	1.20	2.59	0.14	1.62	1.54	1.03	68	83	H6P2
13	1.20	2.64	0.13	1.65	1.61	1.05	67	84	H7P1
14	1.17	2.68	0.13	1.65	1.50	0.93	56	75	H7P2
15	1.16	2.61	0.02	1.50	1.71	0.93	55	87	H8P1
16	1.18	2.61	0.03	1.52	1.70	0.97	58	87	H8P2
17	1.21	2.58	0.06	1.65	1.62	1.03	61	81	H9P1
18	1.21	2.62	0.08	1.74	1.79	1.26	74	91	H9P2
19	1.25	2.73	0.06	1.74	1.91	1.27	72	94	H10P1
20	1.19	2.75	0.06	1.84	1.92	1.34	74	92	H10P2
21	1.25	2.49	0.13	1.53	1.57	1.07	74	90	H11P1
22	1.20	2.56	0.12	1.55	1.73	1.14	73	95	H11P2
23	1.17	2.73	0.01	1.70	1.95	1.23	69	94	H12P1
24	1.21	2.76	0.02	1.46	2.01	1.02	55	94	H12P2
25	1.18	2.64	0.03	1.68	1.84	1.22	72	93	H13P1
26	1.20	2.68	0.03	1.74	1.85	1.25	70	90	H13P2
max	1.25	2.81	0.16	1.84	2.07	1.38	76	100	
xbar	1.20	2.67	0.06	1.63	1.78	1.11	65.3	88.7	
min	1.15	2.49	0.01	1.39	1.50	0.81	46	75	
sigma	0.03	0.08	0.05	0.11	0.16	0.16	8.2	6.2	

2023-07-03--13-35-52--Double Seam: 1 **2023-07-03--13-35-52--Double Seam: 2** **2023-07-03--13-35-52--Double Seam: 3**



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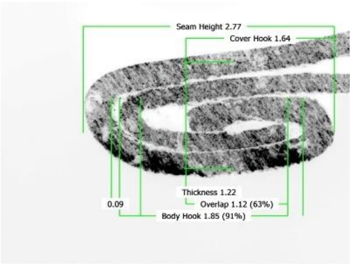

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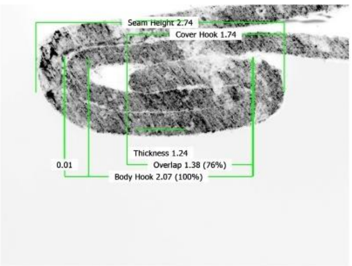

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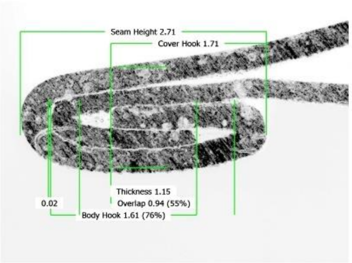

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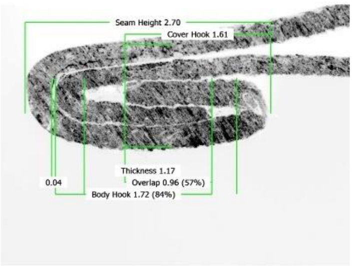

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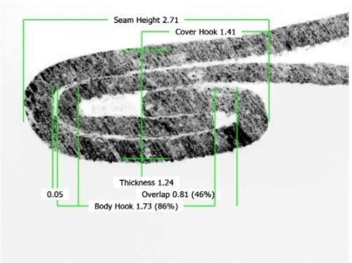

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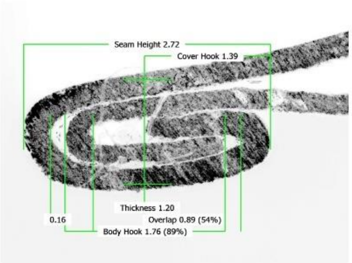

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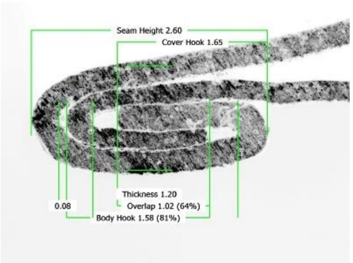

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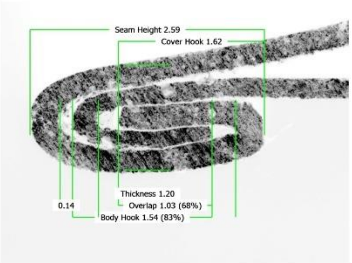

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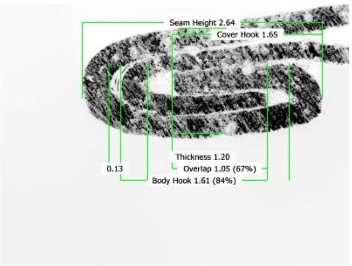
Test: **2023-07-03--13-35-52--Double Seam** **Page 3 of 4**



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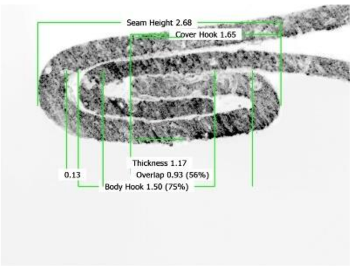

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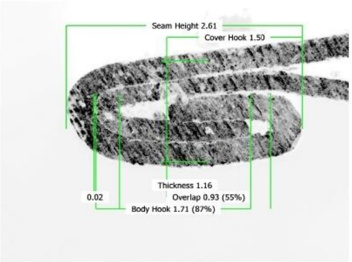

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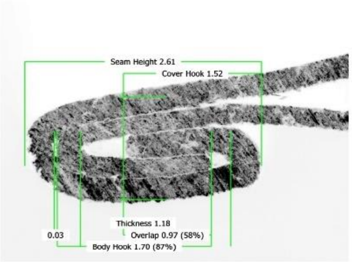

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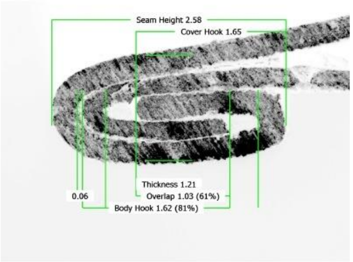

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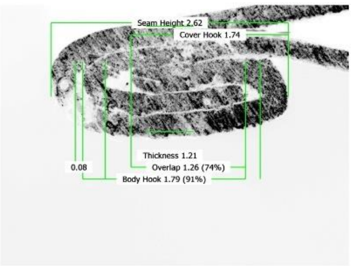

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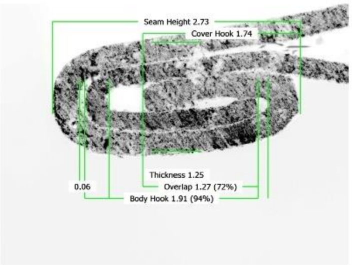

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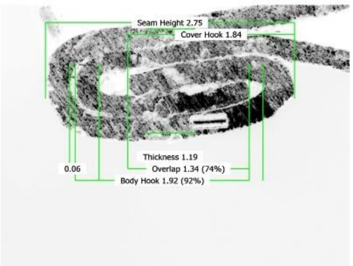

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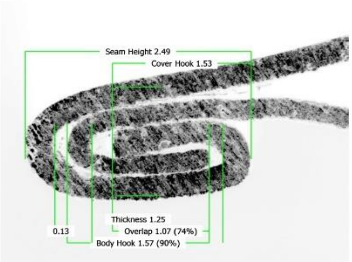

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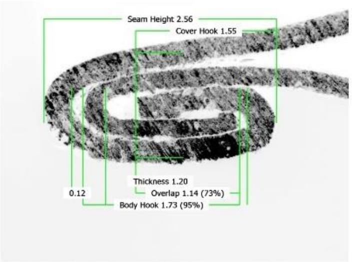

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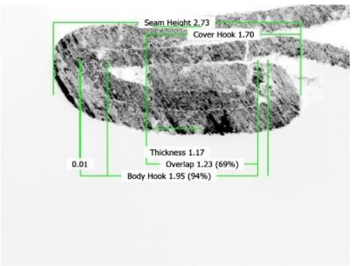

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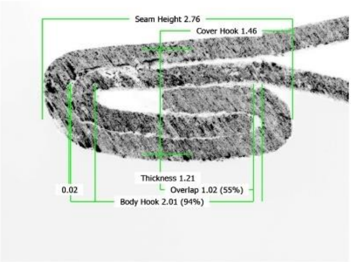

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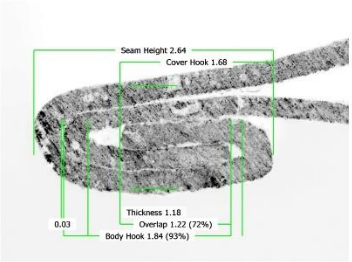

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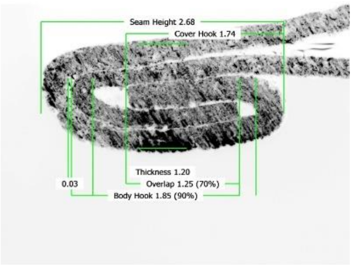

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