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A Study
In the
Production
Of
Creasing Plates

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Summary

This report summarizes the methods of performance and results of a project within production optimizing. The background to the project is the question whether it is possible to improve a current processing line of creasing plates to cut lead time by at least 5 days and if possible making the production more profitable. To get a better understanding of the process a value stream mapping is performed on the production. The data collected is then used to estimate production data for a whole year based on prior order data and calculated specific product factors. The initiator to the project is Tetra Pak Creasing in Lund who is looking at different new ways to enhance their current production processes of creasing tools. The main scope is to reduce processing time, waste and cost while maintaining or even improving the quality of the tools. All tests have been performed at Ferrmek in Simrishamn which is the main supplier of semi-finished creasing plates.

Contents

1 Introduction

1.1 Background

My name is Andreas Eriksson and I am the author of this thesis which is the last part of my education. I have studied Master in Mechanical Engineering with a specialization within production management.

This paper will describe my work with analyze of a sub-contractor production chain for Tetra Pak. The part of Tetra Pak I have been analyzing is the part responsible for creasing plates, which is a tool used in the printing presses at Tetra Pak converting factories around the world. The tool makes a crease in the packaging material to allow the filling machines to work properly.

The thesis was at first intended to include a complete analyses of the whole chain consisting of Uddeholms, KMV, Ferrmek, Brukens and in some part, Tetra Pak Creasing. However, the thesis ended up containing a much deeper analyze of the mechanical work chop Ferrmek and only briefly about Uddeholms and KMV. The reasons to this is mainly the much larger analyze of Ferrmek and a sudden change from KMV to a new subcontractor within the Uddeholms AB.

This thesis will show a deep analyze of costs and problems within the production process of creasing plates and will compare the current process to other possible processing methods.

2 Tetra Pak

2.1 Introducing Tetra Pak

Tetra Pak is the world's largest food processing and packaging solution company. They offers their customers complete solutions from the processing of liquid foods to filled packages ready to be put on shelf in stores. Tetra Pak packages is available in more than 170 countries and every year more than 160 billion packages or 70 billion liter of food or beverages are produced.

The main business is the sales of packaging material and there are 42 converting factories around the world producing the material. [6]

2.2 Tetra Pak Creasing

There are two manufactures producing creasing plates, one in Lund and one in Germany. Tetra Pak Creasing in Lund is the main producer. The creasing plates are used to make a crease in the packaging material to make it fold properly in the filling machine. [4]

2.3 The Supply Chain

The material used to manufacture the tool is steel called Sverker 21 which is delivered by Uddeholms. The tools have a shape of a plate with a radius to fit on rollers inside the printing press. To accomplish the radius of the plate, Uddeholms produces steel shafts in lengths of two meter long rods which they drill making a tube. The tube are then cut up to smaller pieces and annealed to relief tension introduced during drilling. Finally the inner side of the tubes is lathed to the correct thickness of the tube shell.

After this step the base material of the plates are ready and the tubes are sent to Ferrmek where the tubes are cut up into plates. These plates are milled, hardened and finally grinded to the correct thickness and shape before sent to Tetra Pak where the creasing pattern is scintillated into the surface of the plate. [4] [5]

2.4 Order handling

There are three types of orders handled by Tetra Pak Creasing in Lund. Orders regarding spare parts, orders regarding the production of new creasing installations and orders regarding development work of new packages. There are an agreement that Tetra Pak Creasing should have one order every second week to maintain a continually production without disruptions.

Normally the easiest orders to plan are the one for new creasing installations. They are easy to forecast and is always in batches of a complete turn of plates. Spare parts and plates for development work is more difficult to plan, since they are impossible to forecast and sometimes ordered in incomplete batches. Orders regarding new developed packages are also often very urgent and pushed thru with authorization from higher position in the organization which also create a disturbance of the strive for an stable production flow.

To facilitate the order handling a new order system has been introduced and is still relative new for all involved. The system helps with both planning and placing orders. When an order is placed all involved suppliers receives an email containing information about order details, delivery and receiving dates. A fax is also sent as a confirmation of the order. To help the order planer set a correct receiving date to Tetra Pak in Lund, an in house developed Excel planning tool for the EMD machines is used. The order planer at Tetra Pak always strives to maintain full production on the EMD machines all hours of the day. The supplier then complies with this planning. [5]

3 Purpose and Delimitations

3.1 Introducing the Case

The case presented was to perform a Value Stream Mapping on the current production chain to gain a better picture of where there are problems and how big these problems are. The second step was to try to find changes or different methods to make the process easier and faster than today. [4]

3.2 Purpose and Goals

3.2.1 Lead time

The lead time is today about 8 weeks from order to delivery. Tetra Pak Creasing delivers about half of the creasing plates to Examec which is a subcontractor to Tetra Pak assembling new creasing stations tools. The other half is spare part orders from existing processing lines. Tetra Pak Creasing is experiencing an increasing demand of shorter lead times due to shorter lead times in the assembling of new creasing stations. Therefore a reduction of 5 days in lead time would be a desirable goal. [4]

3.2.2 Flexibility

The long lead time doesn’t only results in long waiting time for finished goods. It also makes the process very inflexible and vulnerable since it’s very difficult to produce a new plate if something happened during the production process. This has evoked a rigorous controlling process where every plate is measured many times along the production chain just to make sure nothing goes wrong. The plates are manufactured from tubes where one tube is one turn on a roller in the Creasing station. Since there are many different plates of different wideness and with different radius it’s critical that all plate from a tube get properly manufactured to be able to deliver a complete order. If something happens in the late stages of the process, it can take up to seven weeks to get a new plate ready to complete the order. [4]

3.2.3 Cost

Tetra Pak is always reviewing new ways to cut costs and therefore this is also a desirable goal with this analyze. [4]

3.3 Delimitations

The case is limited to an analysis of the production at Ferrmek. Primary the whole supply chain where to be analyzed, but since the project developed into a deeper analysis of the production at Ferrmek, some limitations had to be made to be able to finish in time. Data from other suppliers needed to complete the analyze is collected by simply asking the suppliers or by using the data already stored at Tetra Pak.

4 Theoretical Framework and Methods

4.1 Lean Production

Lean Production is a production methodology first introduced by Toyota (the Toyota Production System, TPS). The methodology is built on the idea of reducing all waste in the process and focusing the organization on creating value for the end costumer. This method has shown very successful and is now one of the leading methodologies in all kind of companies, large and small. When working with Lean Production there is different tools that can be applied to help facilitate the work. The tools can be applied to all kind of processes and organizations and the one used in this analyze is mentioned in this section. [1] [3]

4.1.1 Value Stream Mapping

One of the main ideas in Lean Production is the idea that all waste within the organization must be identified and reduced. With this demand come many difficulties since it's not always obvious for the people involved to be able to understand what type of processes that can be considered as waste. The Lean Production methodology states that everything not creating a value for the end costumer is considered as waste.

To find this wastes Value Stream Mapping can be used as a analyze method of the process. The process is divided into smaller activities and the time it takes to perform them is measured. Every small activity is then examined and referred to as a value adding or not value adding activity. Every activity considered as not value adding is referred to as waste and should therefore be reduced. An example of a not value adding activity could be looking for a tool in 30 seconds, which is not at all value adding for the end costumer. But when the tool is found and a bolt is mounted on the part, the value for the costumer increases. Value Stream Mapping also helps the user to find small buffers in the productions used to cover different productions problems or cycle differentness. [1] [3]

4.1.2 Just In Time

Working without building large storages in the production and still being able to work with single part production puts very high demands on the control of ordering and delivering of raw material. Single part production demands that the correct parts need to arrive as close as possible to when they are going to be used. Therefore it's very important not to build barriers to suppliers and instead work to get a closer and open collaboration. In the car industry deliveries can be as much as up to a couple per day to prevent storage at the production area. The manufacture states that the goal is to have the storage on the roads in trucks on the way to a factory, instead of in large buildings waiting to be used. [1] [3]

4.1.3 Pull not Push

Another important part to attain a storage free production is to avoid production to storage and instead wait and produce only when an order is placed and there is a real demand. This is important as well as internal in the production where every station after the current, can be looked at as a costumer placing orders when needing a component. The Pull not Push system is facilitated if used with a Can Ban System where a tag is sent backwards I the production when a component is needed. The tag acts like a signal to the prior production station to start the production of a new part. [1] [3]

4.1.4 Continues Improvements

Continues Improvements is one of the cornerstones in the Lean Production way of thinking and ensures the long term profits with this system. Continues Improvements is based on the idea that everyone working within the organization should have a strong willing to improve the way in how the organization works. And not just the way in how the production work but in how the whole organization work regardless of task or process. The way of how to improve should also be based in letting everyone in the organization to lift problems instead of making demands on that they should be solved. The most important is to reveal all problem hidden in the processes and then putting together special teams dedicated to quickly solving the problems. The employees working with the current process is successfully used in the process to attain a solution for the problem since they are involved with the process on a daily basis and best know what will be the best improvements. The employees if involved with the improvement also will feel a greater engagement and will therefore in the future be more anxious to improve their processes. [1] [3]

4.1.5 SMED

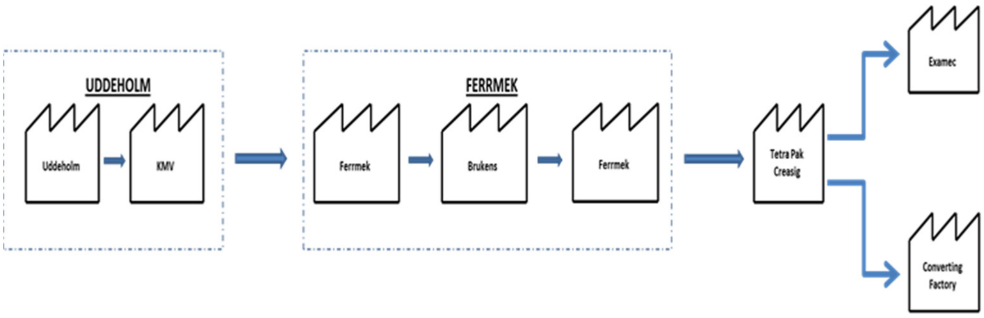
When working with machining or/and assembling, the way the parts that are to be machined or assembled is mounted while processed often makes a huge different. The time it takes to machine or assemble the parts can be seen as value adding time, even if there often is much to do to make it shorter. The time for changing parts between the operations however always is seen as non-value adding activity, and should therefore always be eliminated. Obviously not all time for changing of parts can be eliminated, but the methodology of "SMED" which stands for Single Minute Exchange of Die, states that very often a change between two different parts or products in a machine or assembly line can be made within one minute. This is of course very depending of the current process, and a reachable goal for the process at Ferrmek is set to 10 minutes. [2]

4.2 Six Sigma

To insure a high repeatability it's important to strive for and maintain a static process where the deviations are strictly random. All other factors due to manual handling, temperatures, wear and more that has an effect on the process must be identified and eliminated.

The Six-Sigma method states that the standard deviation of every process step should be no larger than ±1/6 of the tolerance limits. This ensures no more than 3.4 errors per one million produced parts. To be able to obtain this without continues controlling and measuring every part, the effect of manual processing steps must be reduced or controlled by the use of fixtures and, or other tools to eliminate the chance of deviations due to manual handling. Six-Sigma is however considered quite strict and hard to reach, and four-Sigma is therefore a more common used quality level. Four-Sigma ensures not more than 6 210 defect parts of 1 million produced. [1]

5 The Processing chain



5.1 Uddeholms

The manufacturing process of the creasing plates goes through three companies. Uddeholms is the first supplier in the chain and deliver the material in the form of two meter long rods. The rods are delivered to KMV who drills the rods into tubes. The third company is Ferrmek who processes the tubes into plates and uses Brukens to provide the hardening process. The last step in the chain is processed in house at Tetra Pak Creasing, before the plates are finish and sent to end customer. [4]

5.2 KMV

The manufacturing of tubes is done by drilling 2 meter long rods into thin shelved tubes with the diameter required to make the creasing plate fit on the rolls in the creasing station inside the printing press. Tetra Pak offers a wide range of different packages and the variety of creasing patterns are therefore large and requires many different tube diameters. The tubes are cut into smaller tubes and then lathed both inside and outside. Finally the tubes are stress relieved to prevent large deformations during hardening later down the process. [4]

5.3 Ferrmek

Order handling

Orders are sent to Ferrmek mostly by fax which also is complemented by an email containing delivery dates when the plates are expected to arrive at Tetra Pak Creasing in Lund and when Ferrmek expect to receive the tubes from Uddeholms. Since the plates are sent to “Brukens” in Denmark for hardening an order for this has to be created as well. This is handled completely by Ferrmek. [4] [5]

Production

The manufacturing of semi-finished creasing plates is done by milling the approximated crease pattern and various hole for mounting on the roll before finally cutting the tube into single plates. The plates are then hardened and finally grained to proper dimensions. [4]

5.4 Tetra Pak Creasing

The final processing of the crease pattern is done in house at Tetra Pak Creasing in Lund. To obtain the final crease pattern, small edges and ducts are formed by electro discharge machining (EDM). Finally the plates are sandblasted to blunt sharp edges. [4]

6 Value Stream Mapping Ferrmek

To understand the process a Value Stream Mapping (VSM) analyze was performed at the production at Ferrmek.

6.1 VSM

The tubes are delivered to the inbound of Ferrmek where they are stored until usage. The tubes are then milled and cut into plates before they are

hardened. Since plates are sent to hardening only two times a week. A small buffer is built up and therefore seen as a small inventory. After hardening the same level of inventory is created when the plates are pending before the grinding operation. After grinding the plates are gathered to batches of about two whole tubes before they are shipped to Tetra Pak Creasing.
The VSM is done by observing every step in the process from inbound to outbound. All activities are divided into main process activities and every main process activity is then divided into small single activities which is time measured.

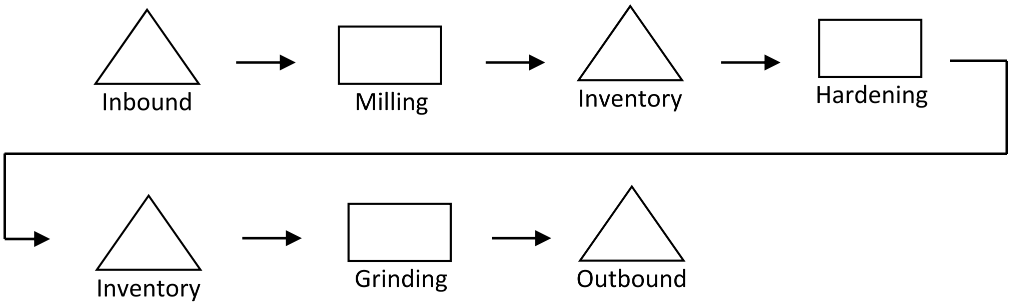


Figure 1 Processing Chain at Ferrmek

The main process activities are:

- Milling
- Hardening
- Grinding

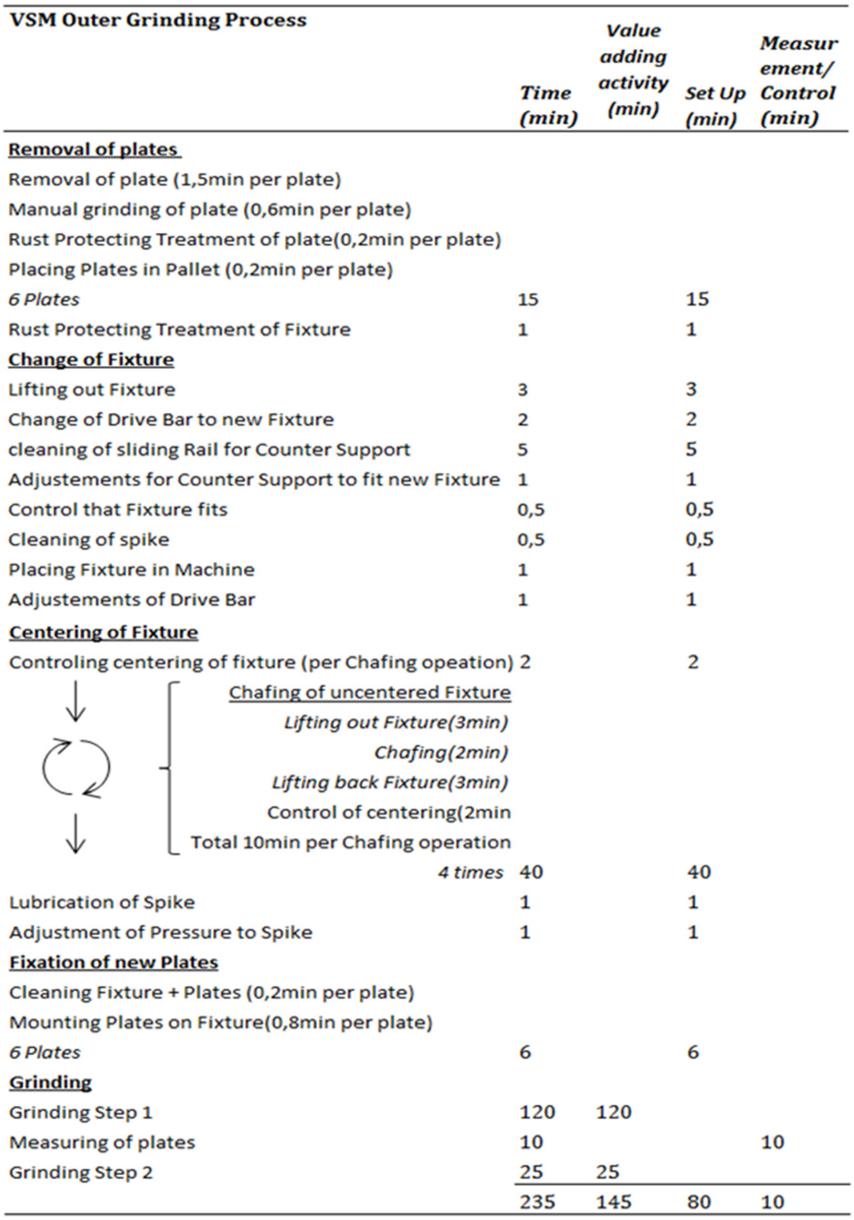
6.1.1 Milling

Ferrmek have one CNC-milling machine used for the production of creasing plates. If any problems, or in special cases, an older milling machine normally not in use can be used to support the existing production line. The ordinary machine is fully automatic and do not need any supervision during operations other for changing tools or tubes. However the operator always supervision the machine since it's very difficult and expensive to get a new tube if the present tube somehow fails. The machine is operated only by one operator and the operator manages only this machine. The plate observed is a 330SQ female plate.

VSM Milling Process	***Time***	***Value adding activity***	***Set Up***	***Control***
Removal of plates	4,00		4,00	
Cleaning with air nozzle	1,00		1,00	
Removal of gavle plates	1,00		1,00	
Fixation of new tube	4,00		4,00	
Change of tools(drill, etc.)	2,00		2,00	
Cleaning pipe	1,00		1,00	
Centering of tube	4,00		4,00	
Nulling the tube at 0° and 180°	2,00		2,00	
Milling	80	80		
Measuring	3			3
Control of cooling water when tool change	0,5			0,5
	102,5	**80,0**	**19,0**	**3,5**

Total time for the milling operation is 102.5 min for this precise plate. Other plates with different diameters require more or less time to finish depending on the shape.

Female plates are always faster since these plates don't have a creasing pattern that needs to be milled out and instead ducts which require less material to be removed than when making the male plates. But it's only the value adding activity that differs. The set up time and measure control time is the same for every type of plates.



VSM Outer Grinding Process	***Time (min)***	***Value adding activity (min)***	***Set Up (min)***	***Measurement/ Control (min)***
Removal of plates				
Removal of plate (1,5min per plate)				
Manual grinding of plate (0,6min per plate)				
Rust Protecting Treatment of plate(0,2min per plate)				
Placing Plates in Pallet (0,2min per plate)				
6 Plates	15		15	
Rust Protecting Treatment of Fixture	1		1	
Change of Fixture				
Lifting out Fixture	3		3	
Change of Drive Bar to new Fixture	2		2	
cleaning of sliding Rail for Counter Support	5		5	
Adjustements for Counter Support to fit new Fixture	1		1	
Control that Fixture fits	0,5		0,5	
Cleaning of spike	0,5		0,5	
Placing Fixture in Machine	1		1	
Adjustements of Drive Bar	1		1	
Centering of Fixture				
Controling centering of fixture (per Chafing opeation)	2		2	
Chafing of uncentered Fixture				
Lifting out Fixture(3min)				
Chafing(2min)				
Lifting back Fixture(3min)				
Control of centering(2min				
Total 10min per Chafing operation				
4 times	40		40	
Lubrication of Spike	1		1	
Adjustment of Pressure to Spike	1		1	
Fixation of new Plates				
Cleaning Fixture + Plates (0,2min per plate)				
Mounting Plates on Fixture(0,8min per plate)				
6 Plates	6		6	
Grinding				
Grinding Step 1	120	120		
Measuring of plates	10			10
Grinding Step 2	25	25		
	235	145	80	10

6.1.2 Grinding

The production line consists of four grinding machines operated by three operators. Two machines for inner grinding and two for outer grinding.

One of each type is semi-automatic and need less supervision then the other two machines which are significantly older and need constant supervision not to fail. The centering of the fixture inside the machine finds special hard as it is done by manual chafing of the fixture mounting holes. The operator can only try its way to a centered fixture and this step in the change of fixture can therefore take all from 10 minutes to several hours.

VSM Inner Grinding Process	***Time (min)***	***Value adding activity (min)***	***Set Up (min)***	***Measurement/ Control (min)***
Change fixture	30		30	
Changing plates				
Measuring of one plate	5			5
Removal of plates (0,5 min per plate)				
Mounting of new plate (0,5 min per plate)				
6 Plates	6		6	
Measuring the edge to ensure the plates are mounted parallell (1 min per plate)				
6 Plates	6			6
Grinding				
Grinding Step 1	120	120		
Untighten bolts to loosening tensions (0,5 min per plate)				
6 Plates	3			3
Measuring the edge to ensure the plates are mounted parallell (1 min per plate)				
6 Plates	6			6
Grinding Step 2	10	10		
Kontroll measuring (0,5 min per plate)				
5 times	2,5			2,5
Grinding betwwen every control (5 min)				
4 times	20	20		
	209	150	36	23

6.1.3 Hardening

The plates are sent to Brukens in Copenhagen for hardening. This process takes 5 working days and the plates are delivered for hardening two times per week, Tuesdays and Thursdays.

6.1.4 Inventory

Only the inbound area is dedicated to storage at Ferrmek, and that’s where the tubes are stored before they are to be milled. However when following the process down the production line there are more places found to be used as mini storage places or buffers. These storage places are pallets placed adjacent to the machines and functioning as small buffers before and after the processing step to even out the differential in processing speed between the stations.

6.1.5 Control and Measurement

Every part is measured several times by hand during each processing step to ensure that too much material isn’t removed. To control that the dimensions are within tolerances, two extra measure stations where more advanced equipment to measure the plates is used. These measures are then documented as proof of accuracy if problem occur when the plates are again measured at Tetra Pak. This because it has happened that Tetra Pak Creasing found some plates to be out of tolerance after EDM-process.

7 Estimation of one year Production

To be able to fully describe the value adding activities at Ferrmek compared to non-valued activities, a three days observation is not enough. This since the data only should be covering a short period of time being insufficient to explain the process in full. The plates are very different in terms of processing time and some plates even have more processing steps then others. Derivations depending on what type of plate is as well causing problems and a very non stable processing flow.

To unhide the actual value of all defects and problems during one year, the processing analyze in this report therefore goes much further using the VSM as a base and then by connecting relations and assumptions in the process calculating a cost estimation for every plate produced during the year 2011.

7.1 Time Estimation of production during 2011

7.1.1 Estimated Milling Time

The milling process for a female plate of this type is 80 min. Since there were no male plates planned to be made, the time consumption for them was estimated by the operator to be 120 min.

$Type\ of\ plate\ during\ observation$: TPA 330 SQ (female)
$Lenght = 201\text{mm}$
$Outer\ diameter = 362{,}54\text{mm}$
$Time\ Milling\ Female = 80\text{min}$
$Time\ Milling\ Male = 120\text{min}$

To be able to estimate the time for different plates a time coefficient were calculated for both male and female plates.

$$k_{milling} = \frac{t_{milling}}{(\emptyset_{outer} * \pi * l_{tube})} \qquad (1)$$

Where:
$t_{milling} = Time\ milling\ one\ tube$
$\emptyset_{outer} = Diameter\ of\ tube$
$l_{tube} = Lenght\ of\ tube$

The coefficients for the milling process are:

$k_{milling\,female} = 349{,}45\ [\mathrm{min/m^2}]$
$k_{milling\,male} = 524{,}18\ [\mathrm{min/m^2}]$

The required time to mill a tube is then calculated by using:

$$t_{milling} = k_{milling} * \emptyset_{outer} * \pi * l_{tube} \qquad (2)$$

The change of tube and controls of dimensions takes

$t_{change\ tube} = 19\mathrm{min}$
$t_{control} = 3{,}5\mathrm{min}$

which together makes the total processing time:

$$t_{total\,process} = t_{milling} + t_{change\ tube} + t_{control} \qquad (3)$$

7.1.2 Estimated Grinding Time Inner

The grinding processes are divided into two operations, inner and outer, where this describes the inner grinding process.
The grinding process for a female plate of type TPA 330 SQ is 145 min and the inner grinding operation does not differ between male and female plates since the inner surface is the same regardless of plate type. The operator states that the machine normally starts 0,9-1mm from the target dimension.

$Type\ of\ plate\ during\ observation\!: TPA\ 330\ SQ\ (female)$
$Lenght = 201\mathrm{mm}$
$Inner\ diameter = 342{,}54\mathrm{mm}$
$Time\ Grinding\ inner = 150\mathrm{min}$

To be able to estimate the time for different types of plates a time coefficient were calculated for both male and female plates.

$$k_{grinding\ inner} = \frac{t_{grinding\ inner}}{(\emptyset_{inner} * \pi * l_{tube})} \tag{4}$$

Where:

$t_{grinding\ inner} = Time\ grinding\ the\ inside\ of\ one\ tube$
$\emptyset_{inner} = Inside\ diameter\ of\ tube$
$l_{tube} = Lenght\ of\ tube$

The coefficients for the grinding process are:

$k_{grinding\ inner} = 693{,}48\ [\mathrm{min/m^2}]$

The required time to grind the inside of a tube is then calculated by using:

$$t_{grinding\ inner} = k_{grinding\ inner} * \emptyset_{inner} * \pi * l_{tube} \tag{5}$$

The change of tube and control of dimensions takes:

$t_{measure\ finished\ plate} = 5$ min per tube
$t_{change\ tube} = 1\mathrm{min}$
$t_{edge\ control\ 1} = 1\mathrm{min}$
$t_{edge\ control\ 2} = 1\mathrm{min}$
$t_{tension\ releve} = 0{,}5\mathrm{min}$
$t_{measure\ control} = 0{,}5\mathrm{min}$
$n_{plates\ per\ tube} =$ number of plates per tube

$$t_{control} = t_{measure\ finished\ plate} + n_{plates\ per\ tube}(t_{edge\ control\ 1} + t_{tension\ releve} + t_{edge\ control\ 2} + t_{measure\ control}) \tag{6}$$

And together makes the total processing time:

$$t_{total\ process} = t_{milling} + t_{change\ tube} + t_{control} \tag{7}$$

If it’s a new order with a different type of tube, a change of fixture as well have to take place:

$t_{change\ fixture} = 30\text{min}$

$$t_{total\ process} = t_{grinding} + t_{change\ tube} + t_{control} + t_{change\ fixture} \qquad (8)$$

7.1.3 Estimated Grinding Time Outer

The outer grinding process is dependent on if it's a male or female plate being processed. For a female plate of type TPA 330 SQ it takes 145 min. Since there were no male plates planned to be made, the time consumption for them was estimated by the operator to be 20% less than female plates. The outer grinding process is also depending on the size of the plate due to deviations after hardening. The deviations drastically increase with sizes close to 1000ml plates and therefore a doubling of the processing time for these types of plates is made.

$Type\ of\ plate\ during\ observation: TPA\ 330\ SQ\ (female)$
$Lenght = 201\text{mm}$
$Outer\ \emptyset = 362{,}54\text{mm}$
$Time\ Grinding\ inner\ female = 145\text{min}$

To be able to estimate the time for different plates a time coefficient were calculated for both male and female plates.

$$k_{grinding\ outer\ female} = \frac{t_{grinding\ outer\ female}}{(\emptyset_{outer} * \pi * l_{tube})} \qquad (9)$$

$$k_{grinding\ outer\ male} = k_{grinding\ outer\ female} * 0{,}8 \qquad (10)$$

Where:

$t_{grinding} = Time\ grinding\ the\ outside\ of\ one\ tube$
$\emptyset_{outer} = Outside\ diameter\ of\ tube$
$l_{tube} = Lenght\ of\ tube$

The coefficients for the grinding process are:

$k_{grinding\ outer\ female} = 633{,}38\ [\text{min/m}^2]$
$k_{grinding\ outer\ male} = 506{,}71\ [\text{min/m}^2]$

The required time to grind a tube is then be calculated by using:

$$t_{grinding} = k_{grinding} * \emptyset_{outer} * \pi * l_{tube} \quad (11)$$

The change of tube and controls of dimensions takes:

$t_{change\ tube}$ = time to change all plates
$n_{plates\ per\ tube}$ = number of plates per tube
$t_{removal\ of\ plate}$ = 2,5 min per plate
$t_{rustprotection\ fixture}$ = 1min
$t_{mounting\ new\ plates}$ = 1min per plate
$t_{measure\ finished\ plate}$ = 10 min per tube

$$t_{change\ tube} = n_{plates\ per\ tube} * (t_{removal\ of\ plates} + t_{rust\ protection\ fixture} + t_{mounting\ new\ plates}) \quad (12)$$

$$t_{control} = t_{measure\ finished\ plate} \quad (13)$$

Total processing time if not changing the fixture:

$$t_{total\ process} = t_{grinding} + t_{change\ tube} + t_{control} \quad (14)$$

If it’s a different type of tube a change of fixture have to take place as well, which always takes different time since this is a process depending on the condition of the fixture and the ability of the operator to know where and how to chafe.

Change of fixture:
$t_{change\ of\ fixture}$ = the time to change to change fixture
$t_{lifting\ out\ fixture}$ = 3min
$t_{change\ of\ drive\ bar}$ = 2min
$t_{cleaning\ of\ sliding\ rail}$ = 5min
$t_{adjustemnt\ counter\ support}$ = 1min
$t_{control\ fixtue\ fits}$ = 0,5min
$t_{cleaning\ of\ spike}$ = 0,5min

$t_{placing\ fixture\ in\ machine} = 1\text{min}$
$t_{adjustments\ of\ drive\ bar} = 1\text{min}$

$$t_{change\ of\ fixture} = t_{lifting\ out\ fixture} + t_{change\ of\ drive\ bar} + t_{cleaning\ of\ sliding\ rail} + t_{adjustemnt\ counter\ support} + t_{control\ fixtue\ fits} + t_{cleaning\ of\ spike} + t_{placing\ fixture\ in\ machine} + t_{adjustments\ of\ drive\ bar} \quad (15)$$

Centering the fixture:
$t_{control\ of\ centering} = 2\text{min}$
$t_{lifting\ out\ fixture} = 3\text{min}$
$t_{chafing} = 2\text{min}$
$t_{lifting\ in\ fixture} = 3\text{min}$
$t_{control\ of\ centering} = 2\text{min}$
$n_{chafing}$ = number of chafing operations

$$t_{centering\ of\ fixture} = t_{control\ of\ centering} + n_{chafing}(t_{lifting\ out\ fixture} + t_{chafing} + t_{lifting\ in\ fixture} + t_{control\ of\ centering}) \quad (16)$$

Total processing time with change of fixture:

$$t_{total\ process} = t_{milling} + t_{change\ tube} + t_{control} + t_{change\ fixture} + t_{centering\ of\ fixture} \quad (17)$$

7.1.4 Estimated Inventory Levels

The inventory levels are estimated by using the estimated processing times together with the actual order data for the year 2011. The time the goods are waiting in inventory or in different buffers along the process is depending on the processing speed of the next machine. Therefore the estimated machine hours are used to calculate the estimated inventory time. Since the estimated machine time is a strictly theoretical value, the time doesn't meet with the time extracted from the production plan which is the real time the material actual where at Ferrmek. The difference between these values assumes to be problems within the manufacturing of the plates and is therefore allocated to the processing operations which then have a direct effect on the time in inventory. The average amount of tubes or plates in inventory is then calculated by using:

$t_{theoretical\ inv}$ = theoretical estimated time in inventory
$t_{total\ pro}$ = total theoretical processing time
n_{gods} = amount of plates or tubes in order
$\bar{n}_{theoretical\ inv}$ = theoretical average amount of plates or tubes in invetory

$$t_{theoretical\ inv} = t_{total\ pro} \tag{18}$$

$$\bar{n}_{theoretical\ inv} = \frac{n_{gods}}{2} \tag{19}$$

To estimate the actual time in inventory the proportion of the actual time the gods were in inventory have to be estimated from the actual time the goods where at Ferrmek. This was done by calculating the total theoretical processing time and from this comparing the theoretical waiting time before and after every operation. Allocation factors where then calculated by comparing the theoretical time in buffer before every operation to the total theoretical time in process at Ferrmek. Then by applying the theoretical allocation factors for every specific waiting event on the actual time at Ferrmek an estimation of how long the products actually where in inventory with care taken for the processing problems is retrieved.

$k_{theoretical\ inv}$ = allocation factor per buffer / inventory
$t_{theoretical\ inv}$ = theoretical time per buffer / inventory
$t_{theoretical\ total}$ = theoretical total inventory time
$t_{actual\ total}$ = actual total time at Ferrmek
$t_{inventory\ actual}$ = actual time in inventory

$$k_{theoretical\ inv} = \frac{t_{theoretical\ inv}}{t_{theoretical\ total}} \tag{20}$$

$$t_{inventory\ actual} = k_{theoretical\ inv} * t_{actual\ total} \tag{21}$$

Since problems in the process sometimes can cause extra waiting time in some areas, this as well has to be taken into consideration when estimating the time in inventory. To do this the actual processing time is compared with the actual delivery time for the next order. If the order isn’t able to start directly the waiting time in inbound is directly added with this extra time and then not taken into account when calculating the other estimations. It is also possible that the problem have been with a machine further down the processing line and therefore the gods in reality where buffered somewhere further down the process. But since it's impossible to retrieve any information about where and when problems occurred or where in the production the gods where buffered during waiting, the extra time in inventory is chosen to affect only on the time in inbound. When analyzing the delivery data, only the arrival and delivery date where to be retrieved.

$t_{milling\ present}$ = processing time milling operation present order
$t_{\_delay}$ = extra waiting time due to problems in production
$d_{next\ delivery}$ = delivery date for next order
$d_{start\ present}$ = start processing date for present order
$t_{inbound\ actual}$ = Actual time in inbound

$$t_{delay} = d_{start\ present} + t_{milling\ present} - d_{next\ delivery} \qquad (22)$$

$$\begin{aligned} t_{\_delay} &= t_{delay} \quad if\ t_{delay} > 0 \\ t_{\_delay} &= 0 \qquad if\ t_{delay} < 0 \end{aligned} \qquad (23)$$

$$t_{inbound\ actual} = t_{milling\ present} + t_{\_delay} \qquad (24)$$

7.1.5 Estimated Waste

In this process there is not much waste in case of material or defect products, most likely due to all control of measure that is made several times during the process. However, controlling is as well a very time consuming activity and can therefore be considered as waste. To estimate the total waste, a comparison between actual and theoretical processing time is done. The theoretical time indicates the smallest theoretical processing time that could be obtained if all wastes where to be removed.

To retrieve the smallest theoretical processing time all known waste is subtracted from the total estimated processing time:

$t_{th\ min\ process} = the\ smallest\ theoretical\ processing\ time$
$t_{th\ setup} = the\ setup\ time\ when\ changing\ order$
$t_{th\ control} = controling\ during\ process\ to\ prevent\ defects$
$t_{th\ measure} = measure\ after\ operation\ to\ confirm$

$t_{act\ other\ waste} = actual\ waste\ hard\ to\ allocate$
$t_{value\ adding\ operation} = Operations\ that\ add\ value\ to\ the\ product$

$$t_{th\ waste} = t_{th\ setup} + t_{th\ control} + t_{th\ measure} \tag{25}$$

or

$$t_{th\ waste} = t_{th\ total\ process} - t_{value\ adding\ operations} \tag{26}$$
$$t_{th\ min\ process} = t_{th\ total\ process} - t_{th\ waste} \tag{27}$$

When observing the actual process only some waste factors can be located and many will still be hidden since no documentation of problems during the year is made. To revile the amount of hidden waste the theoretical minimal processing time is subtracted from the actual total processing time. The waste unable to be seen or estimated during the observation of the process will then be retrieved.

$$t_{act\ waste} = t_{act\ process} - t_{th\ min\ process} \tag{28}$$

Or

$$t_{act\ waste} = t_{th\ waste} + t_{act\ other\ waste} \tag{29}$$

To determine what kind of waste and how much the different types of waste contributes with. The data from the process observation can be used. Allocation factors is calculated for each waste and used to calculate the total waste from the actual processing time.

$$k_{act\ type\ of\ waste} = \frac{t_{act\ type\ of\ waste}}{t_{act\ total\ waste}} \tag{30}$$

7.1.6 Estimated Lead Time

When calculating the lead time only working days are included. When inventories are mentioned and the costs are calculated, every day of the week is included since the interest applies for every day of the year. The lead time is depending on what type of plate that is manufactured with an average of 28 days per order. The lead time for the processing at Ferrmek is the same as total actual processing time.

$$t_{lead\ time} = t_{total\ actual} \tag{31}$$

7.2 Cost Estimation of production during 2011

The costs are calculated based on the estimated processing and inventory times. The total costs for the year was calculated and then allocated on the different orders by allocation factors.

7.2.1 Actual Costs Salaries

Operators Milling, 1 persons	kkr
Total Salary, Ordinary	492
Total Salary, Overtime	-

Operators Grinding, 3 persons	kkr
Total Salary, Ordinary(kkr)	1496
Total Salary, Overtime(kkr)	81,2
Salay, Ordinary/(person*h)(kr)	272

Management, 2 persons	kkr
Total Salary, Ordinary	221
Total Salary, Overtime	12,5

7.2.2 Actual Costs Material

The tubes are bought from Uddeholms and to be able to calculate the cost the cost per one cubic meter material were calculated.

Direct Machine Costs	kkr
Total Machine Costs, 5 machines	50

Tube Costs	
TBA 200 B	
Outer Ø(mm)	311,43
Inner Ø(mm)	271,43
Length(mm)	213,00
Volume(m^3)	0,0039
Cost(kr)	7464,00
Cost/m^3 (kr)	***1913717,83***
TBA 1000 B	
Outer Ø(mm)	312,00
Inner Ø(mm)	272,00
Length(mm)	321,00
Volume(m^3)	0,0059
Cost(kr)	11290,00
Cost/m^3 (kr)	***1917018,00***
Average Cost /m^3(kr)	***1 915 368***
Total Cost Tubes 2011	***4 278 705***

7.2.3 Actual Costs Service

Service includes all type of services made on the machine over the year. Maintenance is made by the operators and is therefore already included in that cost.

Service Costs	
Repair Costs, 5 Machines	30
Maintenance Costs 5 Machines	Included in Operator Costs

7.2.4 Actual Costs Overhead

The management of the creasing plate production is handled by two persons and is estimated to take about 20% of their time per year. The cost is shown earlier under salaries.

Premises Costs		
Total Premises Costs	360	
Premises Costs Milling	36	10%
Premises Costs Grinding	108	30%
Premises Costs Management	72	20%

7.2.5 Estimated Costs Milling

By applying the different costs on to the estimated times for each processes the costs for the manufacturing of every type of creasing plate can be retrieved.

Actual milling cost for the year 2011:

Milling Operation	**kkr**
Depreciation	0,0
Total Direct Machine Costs	10,0
Salary Costs Operators	492,0
Administrative Costs Management	116,8
Premises Costs	72,0
Repair Costs	6,0
Total cost /Year	***696,8***

Fermek have no depreciations left on their machines and therefore this is set to none. When calculating the estimated cost direct cost per hour is used:

Milling Operation	**kkr**
Depreciation(100k/machine)	0,0
Total Machine Costs	10,0
Administrative Costs Management	116,8
Premises Costs	72,0
Repair Costs	6,0
Total cost /Year	***204,8***
Salary Costs Operators /h	272,0

$$t_{milling\ total} = \sum t_{order} = \sum t_{total\ process\ milling} \quad (32)$$

$$k_{allocation} = \frac{t_{order}}{t_{total\ milling}} \quad (33)$$

$$c_{milling\ order} = k_{allocation}(c_{material} + c_{overhead} + c_{service}) + c_{salary} * t_{order} \quad (34)$$

$$c_{milling\ total} = \sum c_{milling\ order} \quad (35)$$

Total actual cost for milling 2011:

$t_{regular} = 1\ 806h$
$t_{overtime} = 0h$
$\boldsymbol{c_{milling\ total}} = \mathbf{696\ 800}\boldsymbol{kr}$

Waiting time due to problems related to Tetra Pak Creasing where during 2011 about 15 percent of the total processing time. The salary cost is estimated to be reduced by this percentage since the operator where used in other orders during this time. The cost for machines however should stay unchanged since the machines where unused.

$t_{regular-wait} = 1\ 806 * 0{,}85 = 1\ 535{,}1h$
$c_{salary-wait} = 1\ 535{,}1 * 272 = 417\ 547{,}2kr$
$c_{milling\ total-wait} = 204\ 800_{process} + 417\ 547_{salery} = \mathbf{622\ 347}\boldsymbol{kr}$

Total estimated theoretical cost for milling:

$t_{milling\ total\ theoretical} = 1\ 034{,}4h$
$c_{salary\ theoretical} = 1\ 034{,}4 * 272 = 281\ 357kr$
$c_{milling\ total\ theoretical} = 204\ 800_{process} + 281\ 357_{salery} = \mathbf{486\ 357}\boldsymbol{kr}$

Total estimated theoretical minimal cost for milling:

$$t_{milling\ total\ min\ theoretical} = 841{,}7h$$
$$c_{salary\ min\ theoretical} = 841{,}7 * 272 = 228\ 942{,}4kr$$
$$c_{milling\ total\ min\ theoretical} = 204\ 800_{process} + 228\ 942{,}4_{salery}$$
$$= \mathbf{433\ 742,4}\boldsymbol{kr}$$

Total estimated theoretical minimal cost for milling with SMED:

$$t_{milling\ total\ min\ theoretical} = 939{,}7h$$
$$c_{salary\ min\ theoretical} = 939{,}7 * 272 = 255\ 598{,}4kr$$
$$c_{milling\ total\ min\ theoretical} = 204\ 800_{process} + 255\ 598{,}4_{salery}$$
$$= \mathbf{460\ 398,4}\boldsymbol{kr}$$

7.2.6 Estimated Costs Hardening

Actual hardening cost for the year 2011:

Hardening	**kkr**
Startup Cost	5,0
Cost Hardening Process /Plate	0,2
Cost Hardening Process /Tube	1,2
Shipping Costs /Batch	1,0
Tubes /Batch	6,0
No. Batches	90
Total cost /plate	***0,4***

The batch size is not static and can vary some due to variations in the process such as machine or delivery problems. However, the delivery to hardening is always carried out two times per week, Tuesdays and Thursdays' with a total sum of 90 batches per year. 2011 where 514 tubes delivered and the average batch size is estimated to about 6 tubes per delivery.

Cost per plate is:

$$c_{hardening} = \mathbf{400}\boldsymbol{kr}$$

Total cost hardening, year 2011 is:

$$c_{hardening\ total} = 400 * 514 * 6 = \mathbf{205\ 600}\boldsymbol{kr}$$

7.2.7 Estimated Costs Grinding

Actual grinding cost for the year 2011:

Grinding Operation	**kkr**
Dereciation	0,0
Total Machine Costs	40,0
Salary Costs Operators	1577,2
Administrative Costs Management	116,8
Premesis Costs	144,0
Repair Costs	24,0
Total cost /Year	***1902,0***

Ferrmek have no depreciations left on their machines and therefore this is set to none. When calculating the estimated cost direct cost per hour is used:

Grinding Operation	**kkr**
Dereciation(100k/machine)	0,0
Total Machine Costs	40,0
Administrative Costs Management	116,8
Premesis Costs	144,0
Repair Costs	24,0
Total cost /Year	***324,8***
Salary Costs Operators /h	272,0

$$t_{grinding\ total} = \sum t_{order} = \sum t_{total\ process\ grinding} \qquad (36)$$

$$k_{allocation} = \frac{t_{order}}{t_{total\ grinding}} \qquad (37)$$

$$c_{grinding\ order} = k_{allocation}(c_{material} + c_{overhead} + c_{service}) + c_{salery} * t_{order} \qquad (38)$$

$$c_{grinding\ total} = \sum c_{grinding\ order} \quad (39)$$

Total actual cost for grinding 2011:

$t_{regular} = 1\ 806h$
$t_{overtime} = 260h$
$\boldsymbol{c_{grinding\ total} = 1\ 902\ 000kr}$
[Appendix A]

Waiting time due to problems related to Tetra Pak Creasing where during 2011 about 15 percent of the total processing time. The salary cost is estimated to be reduced by this percentage since the operators where used in other orders during this time. The cost for machines however should stay unchanged since the machines where unused.

$t_{regular-wait} = 1\ 806 * 0{,}85 = 1\ 535{,}1h$
$c_{salary-wait} = 1\ 535{,}1 * 272 * 3 + 260 * 312 = 1\ 333\ 761{,}6kr$
$c_{grinding\ total-wait} = 324\ 800_{process} + 1\ 333\ 761{,}6_{salery}$
$= \boldsymbol{1\ \ 658\ 561kr}$
[Appendix A]

The production area for grinding consists of four grinding machines, two inner and two outer. Every type of plate (diameter) has its own fixture and can therefore only be processed in one machine at the time. The only exception is for the 1000ml plates where there are two fixtures available for each type of plate. When calculating the total process time for grinding, two parallel orders operated simultaneously have been the normal state.
The 1000ml plates have to be processed two times in each machine and therefore the process times for them are calculated as twice the time.

Total estimated theoretical cost for grinding:

$t_{grinding\ total\ theoretical} = 1\ 226h$
$c_{salary\ theoretical} = 1\ 226 * 272 * 3 = 1\ 000\ 416kr$
$c_{grinding\ total\ theoretical} = 324\ 800_{process} + 1\ 000\ 416_{salery}$
$= \boldsymbol{1\ 325\ 216kr}$
[Appendix A]

Total estimated theoretical minimal cost for grinding:

$$t_{grinding\ total\ theoretical} = 874h$$
$$c_{salary\ theoretical} = 874 * 272 * 3 = 713\ 184kr$$
$$c_{grinding\ total\ theoretical} = 324\ 800_{process} + 713\ 184_{salery}$$
$$= \mathbf{1\ 037\ 984}\boldsymbol{kr}$$

[Appendix A]

Total estimated theoretical minimal cost for grinding with SMED:

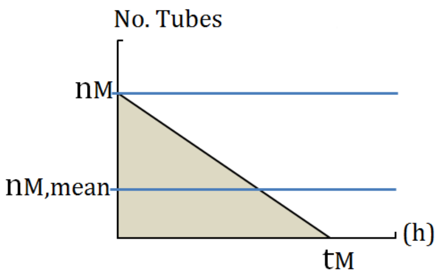
$$t_{grinding\ total\ theoretical\ SMED} = 972h$$
$$c_{salary\ theoretical\ SMED} = 972 * 272 * 3 = 793\ 152kr$$
$$c_{grinding\ total\ theoretical\ SMED} = 324\ 800_{process} + 793\ 152_{salery}$$
$$= \mathbf{1\ 117\ 952}\boldsymbol{kr}$$

[Appendix A]

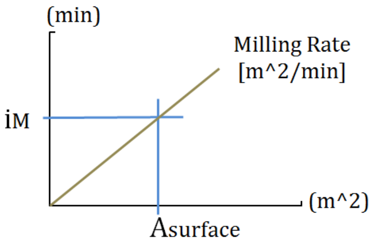
7.2.8 Estimated Costs Inventory

The inventory costs are calculated as the costs due to restricted capital in gods waiting to be processed as well as the goods being processed. The costs associated with wait could direct be labeled as waste. The cost of capital is set to *10%* of all restricted capital in the process.

7.2.8.1 Inbound



▽ *Inbound -> Milling*



☐ *Milling*

$$nM = inventory\ level\ milling$$
$$nM, mean = Average\ inventory\ level\ milling$$

$tM = time\ to\ empty\ inventory\ lmilling$
$iM = Miling\ speed$
$Asurface = Area\ of\ surface\ to\ be\ processed$
Cost of capital due to restricted capital in goods waiting to be processed:

$$c_{CoC\ inbound} = \frac{(\bar{n}_{tubes\ in\ inventory} * c_{total\ value\ tubes} * i_{10\%})}{360} * t_{time\ in\ inbound} \quad (40)$$

Cost of capital due to restricted capital in goods during process:

$$c_{CoC\ process} = \frac{(\bar{n}_{tubes} * c_{total\ value\ tubes} * i_{10\%})}{360} * t_{time\ in\ milling\ process} \quad (41)$$

Cost of capital due to the milling process:

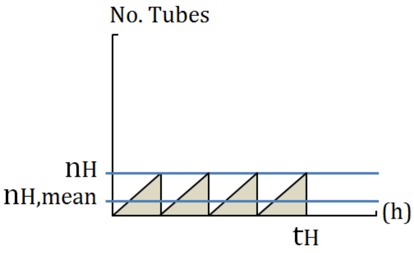
$$c_{CoC\ operation} = \frac{(c_{milling} * i_{10\%})}{360} * t_{time\ in\ milling\ process} \quad (42)$$

The total Cost of capital due to all restricted capital:

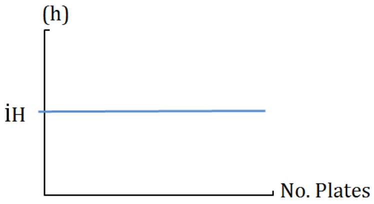
$$c_{CoC\ total} = \sum (c_{coc\ milling} + c_{coc\ inbound} + c_{coc\ operation})_{order} \quad (43)$$

$c_{CoC\ inbound} = 7\ 410 kr$
$c_{CoC\ process} = 7\ 410 kr$
$c_{CoC\ operation} = 1\ 218 kr$
$c_{CoC\ total} = \mathbf{16\ 038 kr}$
[Appendix C]

7.2.8.2 Waiting for Hardening



▽ *Outbound -> Hardening*



▭ *Hardening*

$nH = \textit{inventory level outbound}$
$nH, mean = \textit{Average inventory level outbound}$
$tH = \textit{time to empty inventory outbound}$
$iH = \textit{hardening speed}$

Cost of capital due to restricted capital in goods waiting to be processed:

$$c_{CoC\ outbound} = \frac{(\bar{n}_{tubes\ in\ outbound} * c_{total\ value\ tubes} * i_{10\%})}{360} * t_{time\ in\ outbound} \tag{44}$$

Cost of capital due to restricted capital in goods during process:

$$c_{CoC\ process} = \frac{(\bar{n}_{tubes} * c_{total\ value\ tubes} * i_{10\%})}{360} * t_{time\ in\ hardening\ process} \tag{45}$$

Cost of capital due to the hardening process:

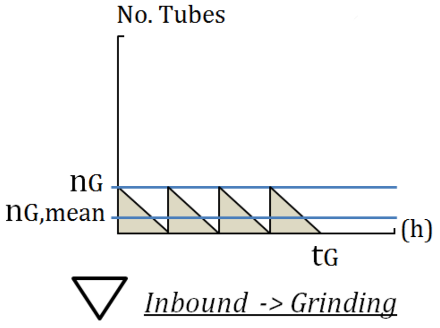
$$c_{CoC\ operation} = \frac{(c_{hardening} * i_{10\%})}{360} * t_{time\ in\ hardening\ process} \tag{46}$$

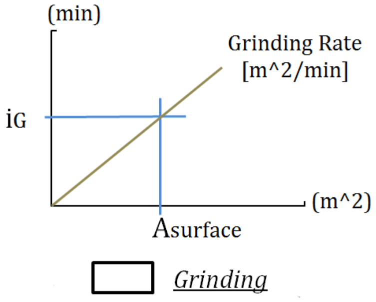
The total Cost of capital due to all restricted capital:

$$c_{CoC\ total} = \sum \left(c_{coc\ hardening} + c_{coc\ oubound} + c_{coc\ operation}\right)_{order} + c_{coc\ total\ milling}) \tag{47}$$

$c_{CoC\ outbound} = 5\,788kr$
$c_{CoC\ process} = 3\,963kr$
$c_{CoC\ operation} = 1\,766kr$
$c_{CoC\ total} = \mathbf{27\,554kr}$
[Appendix C]

7.2.8.3 *Waiting for Grinding*





$nG = inventory\ level\ grinding$
$nG, mean = Average\ inventory\ level\ grinding$
$tG = time\ to\ empty\ inventory\ grinding$
$iG = Grinding\ speed$
$Asurface = Area\ of\ surface\ to\ be\ processed$

Cost of capital due to restricted capital in goods waiting to be processed:

$$c_{CoC\ inbound} = \frac{(\bar{n}_{tubes\ in\ inbound} * c_{total\ value\ tubes} * i_{10\%})}{360} * t_{time\ in\ inbound} \quad (48)$$

Cost of capital due to restricted capital in goods during processed:

$$c_{CoC\ process} = \frac{(\bar{n}_{tubes} * c_{total\ value\ tubes} * i_{10\%})}{360} * t_{time\ in\ grinding\ process} \quad (49)$$

Cost of capital due to the milling process:

$$c_{CoC\ operation} = \frac{(c_{grinding} * i_{10\%})}{360} * t_{time\ in\ grinding\ process} \quad (50)$$

The total Cost of capital due to all restricted capital:

$$c_{CoC\ total} = \sum \big(c_{coc\ grindin} + c_{coc\ inbound} + c_{coc\ operation}\big)_{order} + c_{coc\ total\ milling} + c_{coc\ total\ hardening}\big) \quad (51)$$

$c_{CoC\ inbound} = 2\ 733kr$

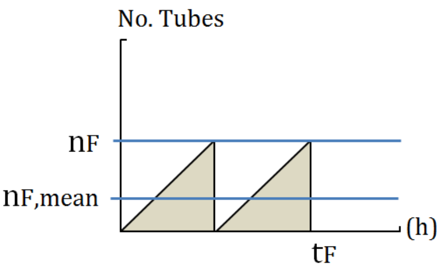
$c_{CoC\ process} = 2\ 733kr$

$c_{CoC\ operation} = 1\ 234kr$

$c_{CoC\ total} = \mathbf{34\ 253kr}$

[Appendix C]

7.2.8.4 Outbound



▽ *Outbound Finished Plates*

$nF\ = inventory\ level\ outbound$
$nF, mean = Average\ inventory\ level\ outbound$
$tF\ = time\ to\ empty\ inventory\ outbound$

Cost of capital due to restricted capital in goods waiting to be processed:

$$c_{CoC\ outbound} = \frac{(\bar{n}_{tubes\ in\ outbound} * c_{total\ value\ tubes} * i_{10\%})}{360} * t_{time\ in\ inbound} \qquad (52)$$

The total Cost of capital due to all restricted capital:

$$c_{CoC\ total} = \sum (c_{coc\ outbound})_{order} + c_{coc\ total\ milling} + c_{coc\ total\ hardening} + c_{coc\ total\ grinding}) \qquad (53)$$

$c_{CoC\ outbound} = 566kr$
$c_{CoC\ total} = \mathbf{34\,819}\boldsymbol{kr}$
[Appendix C]

7.3 Time and Cost Comparison

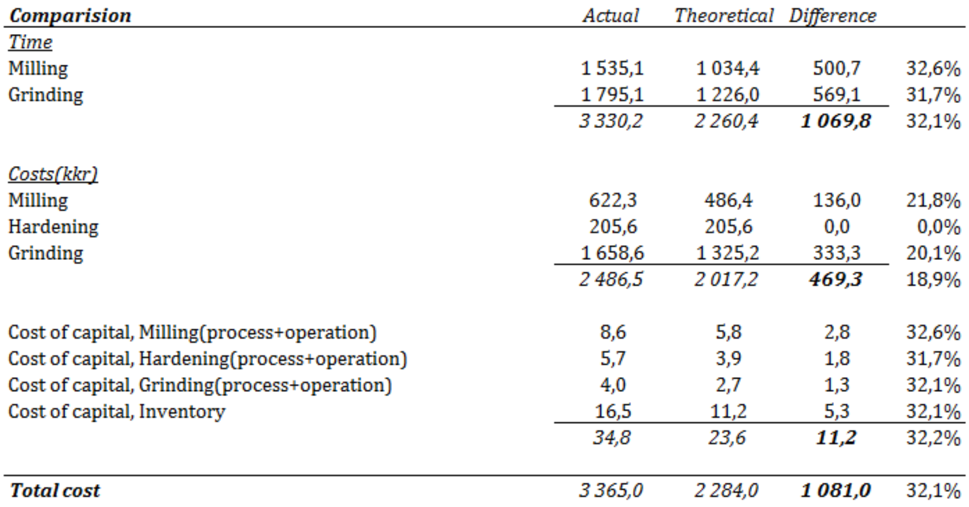
For the year 2011, following time and costs were retrieved from Ferrmek regarding working hours and salary related to the process of manufacturing creasing plates at Ferrmek.

Labor hours and Salaries 2011	*Actual*	*(-)wait*
Time		
Milling, ordinary	1806	1535,1
Milling, overtime	0	0
		1535,1
Salay		
Milling, ordinary salary	272	417547,2
Milling, overtime 1 salary	312	0
		417547,2
Time		
Grinding, ordinary	1 806	1535,1
Grinding, overtime	260	260
		1795,1
Salay		
Grinding, ordinary salary(3 operators)	272	1252641,6
Grinding, overtime 1 salary(1 operator)	312	81120
		1333762
Time		
Managemnet, ordinary	810	688,5
Managemnet, overtime	40	40
		728,5
Salay		
Managemnet, ordinary salary	272	187272
Managemnet, overtime salary	312	12480
		199752

[Appendix A,B,C]

7.3.1 Estimated Production Time 2011

When comparing the actual data with the theoretical estimated data from the analyze an indication of possible areas within the process where improvements can be made are shown. These data, however isn't absolute and can vary in some aspects but are still a very good indicator of where in the process there are problems, and how large the possible profit could be. Since Ferrmek have problems hard to point out and impossible to see during a short visit, the first data to look at is the actual times spend by workers in the process of manufacturing creasing plates during 2011. This time are compared with the theoretical estimated time it should take to produce the exact same amount of plates if the production where to be exactly the same as during the visit. No possible improvements are included within the "theoretical time". The time for changing tools and plates are the same as today and the time the machines take to process the plates are equal to present.



Comparision	*Actual*	*Theoretical*	*Difference*	
Time				
Milling	1 535,1	1 034,4	500,7	32,6%
Grinding	1 795,1	1 226,0	569,1	31,7%
	3 330,2	*2 260,4*	***1 069,8***	32,1%
Costs(kkr)				
Milling	622,3	486,4	136,0	21,8%
Hardening	205,6	205,6	0,0	0,0%
Grinding	1 658,6	1 325,2	333,3	20,1%
	2 486,5	*2 017,2*	***469,3***	18,9%
Cost of capital, Milling(process+operation)	8,6	5,8	2,8	32,6%
Cost of capital, Hardening(process+operation)	5,7	3,9	1,8	31,7%
Cost of capital, Grinding(process+operation)	4,0	2,7	1,3	32,1%
Cost of capital, Inventory	16,5	11,2	5,3	32,1%
	34,8	*23,6*	***11,2***	32,2%
Total cost	*3 365,0*	*2 284,0*	***1 081,0***	32,1%

[Appendix A, B, C]

The comparison indicates that there are problems within the production that couldn't be discovered during the visit and maybe more important does they show that Ferrmek as well isn't aware about them. Possible problems could be due to non-effective use of machines between orders or much longer tool or parts changes then shown during the visit.

7.3.2 Minimum Theoretical Production Time

To get an indication of the overall theoretical possible improvement there are to be made if the production should work as it should if it was to be considered as "LEAN", the "absolute theoretical minimal processing time" can be calculated and compared to the "theoretical time".

Comparision	*Theoretical*	*minimal*	*Difference*	
Time				
Milling	1 034,4	841,7	192,7	18,6%
Grinding	1 226,0	874,0	352,0	28,7%
	2 260,4	*1 715,7*	***544,7***	24,1%
Costs(kkr)				
Milling	486,4	433,7	52,6	10,8%
Hardening	205,6	205,6	0,0	0,0%
Grinding	1 325,2	1 038,0	287,2	21,7%
	2 017,2	*1 677,3*	***339,9***	16,8%
Cost of capital, Milling(process+operation)	5,8	4,7	1,1	18,6%
Cost of capital, Hardening(process+operation)	3,9	2,8	1,1	28,7%
Cost of capital, Grinding(process+operation)	2,7	2,0	0,6	24,1%
Cost of capital, Inventory	11,2	8,5	2,7	24,1%
	23,6	*18,1*	***5,6***	23,5%
Total cost	*2 284,0*	*1 733,8*	***550,3***	24,1%

[Appendix A,B,C]

This times is calculated without any time for tool changes or changes of parts and are therefore not realistic. However, it's still very useful data, not only that it is a great data to benchmark against when looking for possible operations in the process to improve. But as well when trying to find good goals to work towards during the improvement work.

7.3.3 Minimum Feasible Production Time

SMED, stands for “a Single Minute Exchange of Die” and states that very often a change of tool or part in an operation shouldn’t need to take more than 1-10 minutes to execute.

Therefore if adding 10 minutes to the absolute minimum processing time for every change of order, tool or plates. The most lean and possible process are calculated. These processing times is then compared to the “theoretical time” and if the difference is large, there are most likely possible improvement to be made to the process.

Comparision	*Theoretical*	*SMED (max 10min)*	*Difference*	
Time				
Milling	1 034,4	939,7	94,7	9,2%
Grinding	1 226,0	972,0	254,0	20,7%
	2 260,4	*1 911,7*	***348,7***	15,4%
Costs(kkr)				
Milling	486,4	460,4	26,0	5,3%
Hardening	205,6	205,6	0,0	0,0%
Grinding	1 325,2	1 118,0	207,3	15,6%
	2 017,2	*1 784,0*	***233,2***	11,6%
Cost of capital, Milling(process+operation)	5,8	5,3	0,5	9,2%
Cost of capital, Hardening(process+operation)	3,9	3,1	0,8	20,7%
Cost of capital, Grinding(process+operation)	2,7	2,3	0,4	15,4%
Cost of capital, Inventory	11,2	9,5	1,7	15,4%
	23,6	*20,1*	***3,5***	14,8%
Total cost	*2 040,8*	*1 804,1*	***236,7***	11,6%

[Appendix A, B, C]

7.3.4 Minimum Feasible Production Time compared to Actual

Comparing the estimated values when taking into account the 10 minutes for change of fixture, shows the minimal feasible potential of improvements possible to be made. This is the actual difference there is between how the production works today compared to how it could work if it was to be considered as "LEAN".

Comparision	*Actual*	*SMED (max 10min)*	*Difference*	
Time				
Milling	1 535,1	939,7	595,4	38,8%
Grinding	1 795,1	972,0	823,1	45,9%
	3 330,2	*1 911,7*	***1 418,5***	42,6%
Costs(kkr)				
Milling	622,3	460,4	161,9	26,0%
Hardening	205,6	205,6	0,0	0,0%
Grinding	1 658,6	1 118,0	540,6	32,6%
	2 486,5	*1 784,0*	***702,6***	28,3%
Cost of capital, Milling(process+operation)	8,6	5,3	3,3	38,8%
Cost of capital, Hardening(process+operation)	5,7	3,1	2,6	45,9%
Cost of capital, Grinding(process+operation)	4,0	2,3	1,7	42,6%
Cost of capital, Inventory	16,5	9,5	7,0	42,6%
	34,8	*20,1*	***14,7***	42,2%
Total cost	*2 521,3*	*1 804,1*	***717,2***	28,4%

[Appendix A, B, C]

7.3.5 Lead time

The lead time at Ferrmek is today about 23 days if calculating on the median value of all delivered orders. When looking at the average value, the lead time is 28 days due to some orders talking far longer time than ordinary. The milling and grinding operations have possible improvements of up to more than 30% of present processing time, which then would have an direct effect on the lead time as well.

$\bar{t}_{milling} + \bar{t}_{grinding} = 18\ days$
$\bar{t}_{hardening} = 5\ days$
$t_{current\ lead\ time} = 23\ days$

$$t_{current\ lead\ time} = \bar{t}_{milling} + \bar{t}_{hardening} + \bar{t}_{grinding} \tag{54}$$

$$t_{theoretical\ lead\ time} = \bar{k}_{-\ 32\%}\left(\bar{t}_{milling} + \bar{t}_{grinding}\right) + \bar{t}_{hardening} \tag{55}$$

$$t_{theoretical\ lead\ time\ SMED} = \bar{k}_{-\ 43\%}\left(\bar{t}_{milling} + \bar{t}_{grinding}\right) + \bar{t}_{hardening} \tag{56}$$

$t_{current\ median\ lead\ time} = 23\ working\ days$
$t_{theoretical\ everage\ lead\ time} = 17\ working\ days$
$t_{theoretical\ everage\ lead\ time\ SMED} = 15\ working\ days$

[Appendix A, B, C]

8 Possible New production methods

When first introduced to the thesis, Tetra Pak as well wanted it to cover a test of a different manufacturing method of creasing plates. The project then would become too large to be covered within the same thesis, and where therefore split into two different reports. Since the reader might find it interesting to learn of and compare a new method to the one described here, this thesis will as well cover some of this comparisons. Deeper information's of test validations and data can be found in "A study in Hot Forming of High Strength Steel" which is found in Appendix D.
[Appendix D]

8.1 Hot forming without Hardening

Hot forming of iron plates is a possible way to form a creasing plate without the need of tubes and thereby significant decreasing waste and lead time. If the plates aren't treated over ~1050 ˚C the steel isn't hardened and further processing will be easier and require less time.

As always it is important to keep deviations as small as possible to prevent large and time consuming secondary processing steps. The forming method described in the report "A study in Hot Forming of High Strength Steel", are based on a method where two iron tools are pressed together with a plate in between by approximately 350 tons of pressure, shaping the plate to its desired form.

When using this method the deviations became quit large because of large inner tension which causes the material to change dimension when heated to be hardened. The cost of large deviations is high due to long processing times when trying to correct hardened steel by grinding.
[Appendix D]

8.2 Hot Forming and Hardening in same process

Hot forming and hardening in the same process step is where the plate is heated to its temperature where it starts to form martensite. It is then, while being formed in the press, cooled rapidly and therefore hardened. This type

of forming as well need an extra heat treatment, “annealing”, to make the plates more ductile and keeping them from self-cracking of high inner tensions.
However, the method gives much less deviations and therefore saves time. The only setback is that the continuing processing of the plates becomes much more difficult do to the hardness of the plates of up to 63 HRC. These could however be solved by using a pre-pressing step, where the plates are pressed in radiuses close to the final dimensions.

Drilling and milling could then be done before the plate finally is heated and formed to satisfying dimensions. By doing this the deformation of drilled holes is reduced when heat forming the plate. The small deformation can then be corrected in an EDM machine which is a slow but fully automated process and therefore relative cheap.
[Appendix D]

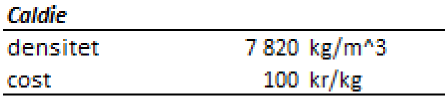
8.3 Comparing Cost of possible Production Method

8.3.1 Costs of different Production Methods

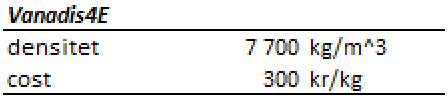
In both of these scenarios, Ferrmek would need to have an inventory to obtain its own production of raw plate material without buying tubes in different diameters. This inventory could contain of material in the form of large steel sheets which is cut up in smaller pieces and formed as creasing plates with desired radius.

Two different materials are tested in the report “A study in Hot Forming of High Strength Steel”. Caldie and Vanadis 4 Extra, which both are steels delivered from Uddeholms.

Cost of material:

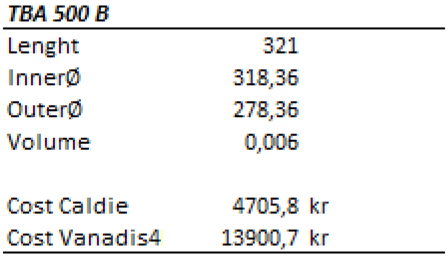


Caldie	
densitet	7 820 kg/m^3
cost	100 kr/kg



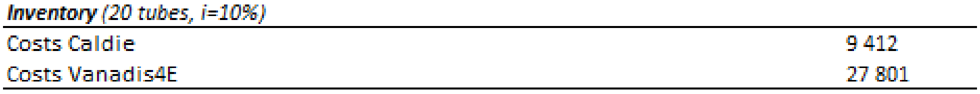
Vanadis4E	
densitet	7 700 kg/m^3
cost	300 kr/kg

The cost for a whole tube of plates with dimensions as for a TBA 500b plate is:



TBA 500 B		
Lenght	321	
InnerØ	318,36	
OuterØ	278,36	
Volume	0,006	
Cost Caldie	4705,8	kr
Cost Vanadis4	13900,7	kr

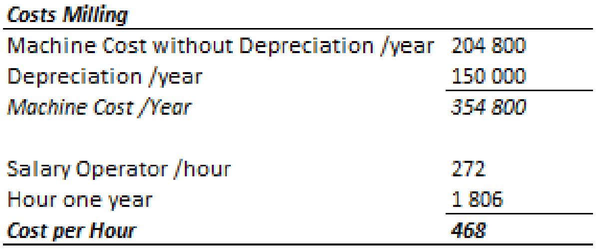
The cost for an inventory of 20 tubes is then estimated to:



Inventory *(20 tubes, i=10%)*	
Costs Caldie	9 412
Costs Vanadis4E	27 801

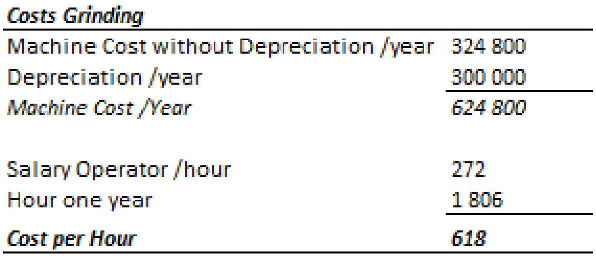
Other costs that affect the comparison of methods are costs for machines needed in the production. Since Fermek doesn't have any depreciation left on their machines the costs today are very low. However to be able make an investment appraisal, annual costs for depreciations have to be taken into account. Following costs are calculated on 10 year depreciation.

Cost per hour of using the Milling Machine:



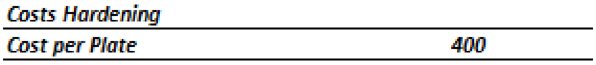
Costs Milling	
Machine Cost without Depreciation /year	204 800
Depreciation /year	150 000
Machine Cost /Year	*354 800*
Salary Operator /hour	272
Hour one year	1 806
Cost per Hour	***468***

Cost per hour of using the Grinding Machine:



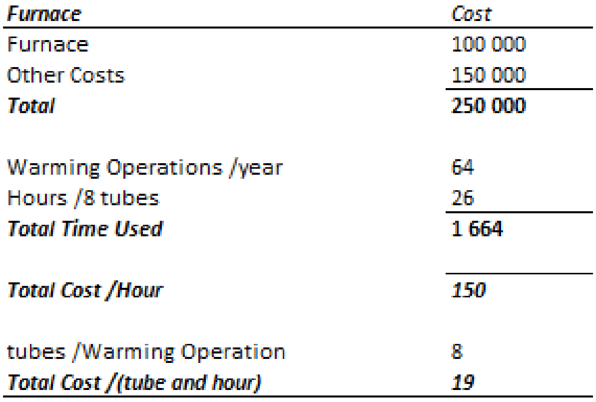
Costs Grinding	
Machine Cost without Depreciation /year	324 800
Depreciation /year	300 000
Machine Cost /Year	*624 800*
Salary Operator /hour	272
Hour one year	1 806
Cost per Hour	***618***

Cost per plate for Hardening:



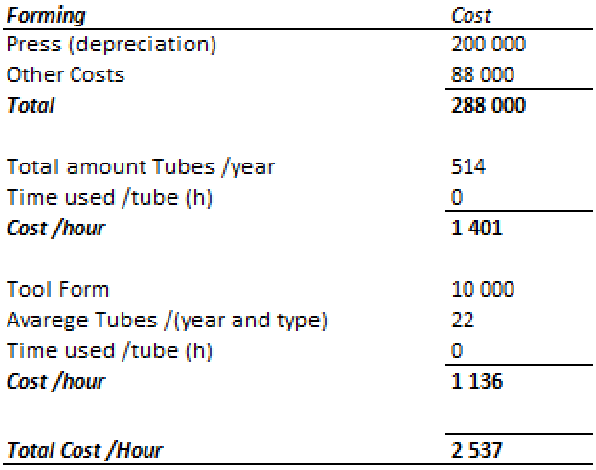
Costs Hardening	
Cost per Plate	***400***

Cost per hour of using the Furnace:



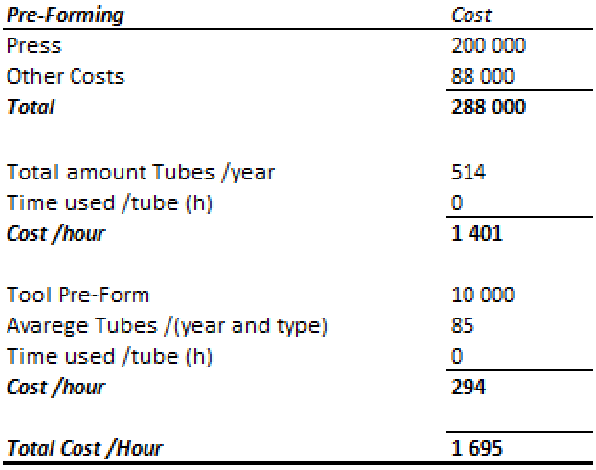
Furnace	*Cost*
Furnace	100 000
Other Costs	150 000
Total	**250 000**
Warming Operations /year	64
Hours /8 tubes	26
Total Time Used	**1 664**
Total Cost /Hour	***150***
tubes /Warming Operation	8
Total Cost /(tube and hour)	***19***

Cost per hour of Forming:



Forming	*Cost*
Press (depreciation)	200 000
Other Costs	88 000
Total	**288 000**
Total amount Tubes /year	514
Time used /tube (h)	0
Cost /hour	**1 401**
Tool Form	10 000
Avarege Tubes /(year and type)	22
Time used /tube (h)	0
Cost /hour	**1 136**
Total Cost /Hour	**2 537**

Cost per hour of Pre-Forming:



Pre-Forming	*Cost*
Press	200 000
Other Costs	88 000
Total	**288 000**
Total amount Tubes /year	514
Time used /tube (h)	0
Cost /hour	**1 401**
Tool Pre-Form	10 000
Avarege Tubes /(year and type)	85
Time used /tube (h)	0
Cost /hour	**294**
Total Cost /Hour	**1 695**

In the report, “A study in Hot Forming of High Strength Steel” the deviations from the test of forming both materials is presented and the extra thickness needed to guarantee a production quality of 4 sigma is calculated.

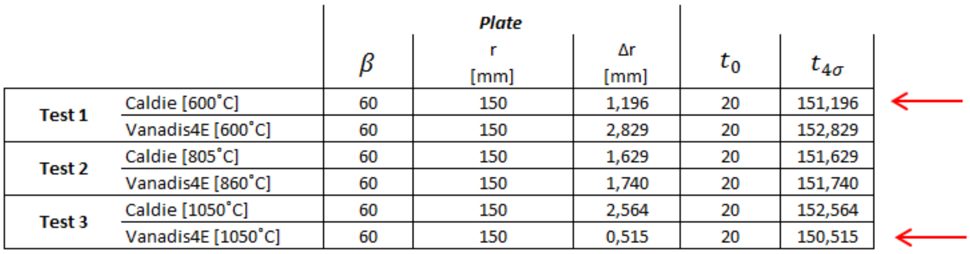
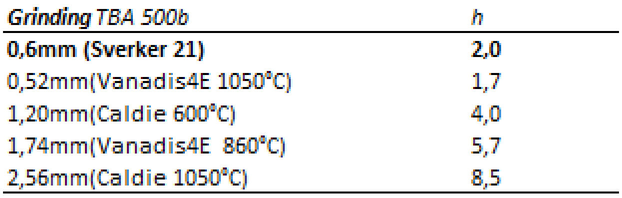


			Plate			
		β	r [mm]	Δr [mm]	t_0	$t_{4\sigma}$
Test 1	Caldie [600˚C]	60	150	1,196	20	151,196
	Vanadis4E [600˚C]	60	150	2,829	20	152,829
Test 2	Caldie [805˚C]	60	150	1,629	20	151,629
	Vanadis4E [860˚C]	60	150	1,740	20	151,740
Test 3	Caldie [1050˚C]	60	150	2,564	20	152,564
	Vanadis4E [1050˚C]	60	150	0,515	20	150,515

[Appendix D]

When estimating the cost for alternative production methods where newer materials will be used, the extra thicknesses due to different deviations have to be taken into account when estimating the grinding costs. During the Value Stream Mapping the plates where 0.6 mm thicker than its final dimensions to make it possible to obtain correct thickness, and the time to grind different thicknesses are estimated based on that.



Grinding TBA 500b	*h*
0,6mm (Sverker 21)	**2,0**
0,52mm(Vanadis4E 1050°C)	1,7
1,20mm(Caldie 600°C)	4,0
1,74mm(Vanadis4E 860°C)	5,7
2,56mm(Caldie 1050°C)	8,5

[Appendix D]

8.3.2 Costs of Hot Forming

The cost of an improved production line together with the new hot forming method is calculated based on investments of some new equipment's such as a cutting machine for the large steel blanks. This cost is estimated to be the same as for a milling machine.

The estimated production cost per tube and material is then calculated and compared to the present production costs.

Caldie

Improved Produktion at Ferrmek + Hot Forming

Leadtime and Cost, 1 tube TBA 500b, Caldie	*h*	Days	Cost/h	Total Cost
Cut up Blanks	*1,00*	0,13	469	469
Warming	*2,00*	0,25	19	38
Forming	0,20	0,03	2 537	507
Stress Relief	22,00	0,92	19	413
Milling	2,20	0,28	468	1 031
Hardening	26,00	3,25		400
Grinding	4,00	0,50	618	2 472
total(h)	**54**	**5**		**5 329**
Material Cost Caldie				4 706
Total Cost /tube				**10 035** ←

[Appendix A, B, C]

Vanadis 4 Extra

Improved Produktion at Ferrmek + Hot Forming

Leadtime and Cost, 1 tube TBA 500b, Vanadis4E	*h*	Days	Cost/h	Total Cost
Cut up Blanks	*1,00*	0,13	469	469
Warming	*2,00*	0,25	19	38
Forming	0,20	0,03	2 537	507
Stress Relief	22,00	0,92	19	413
Milling	2,20	0,28	468	1 031
Hardening	26,00	3,25		400
Grinding	5,70	0,71	618	3 522
total(h)	**56,10**	**5,18**		**6 380**
Material Cost Vanadis4E				13 901
Total Cost /tube				**20 280**

[Appendix A, B, C]

For the method of hot forming without hardening, Caldie has the lowest rate of deviations as well as the lowest price of material.

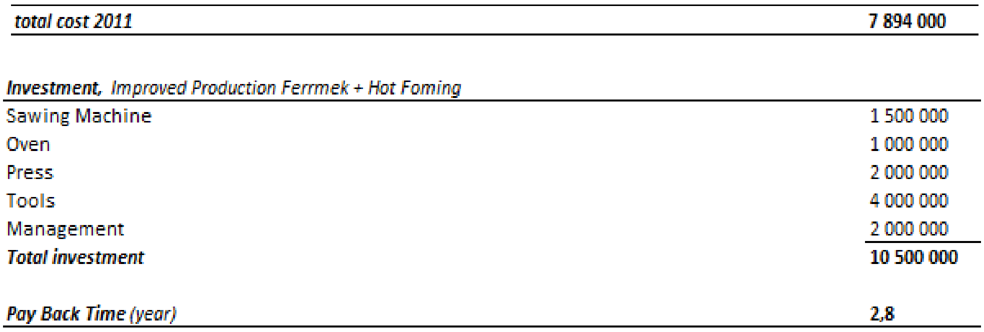
Current Production	*h*	Days	Cost
Uddeholm	104	13	11 526
Ferrmek	56	7	7 830
total	**160**	**20**	**19 356**

Improved Production	*h*	Days	Cost
Uddeholm	104	13	11 526
Ferrmek	46	6	6 418
total	**150**	**19**	**17 944**

[Appendix A, B, C]

Compared to current production methods when using Sverker 21, the Caldie material shows great potential of cost reductions. But the Vanadis 4 Extra would actually be more expensive. The lead time however is reduced by almost 75% in both cases.

The payback time is calculated by comparing the actual estimated annual cost for the year 2011 with the estimated total cost of investments of a new production setup.



total cost 2011	**7 894 000**

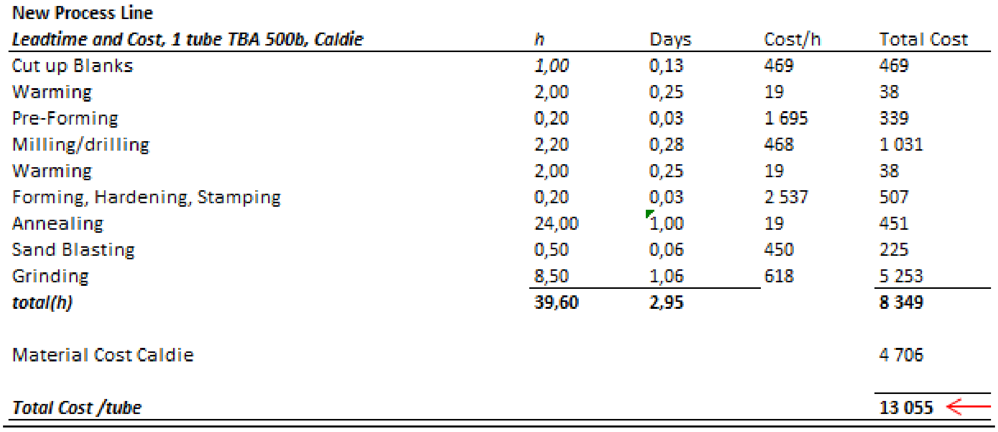
Investment, *Improved Production Ferrmek + Hot Foming*	
Sawing Machine	1 500 000
Oven	1 000 000
Press	2 000 000
Tools	4 000 000
Management	2 000 000
Total investment	**10 500 000**
Pay Back Time *(year)*	**2,8**

The payback time of this investment would be approximately 3 years.

8.3.3 Costs of Hot Forming and Hardening

The method of using hot forming and hardening in the same processing step would require a whole new setup of production line. The total investment cost however wouldn't differ much from the other method since its only requires one extra set of forming station.

Caldie

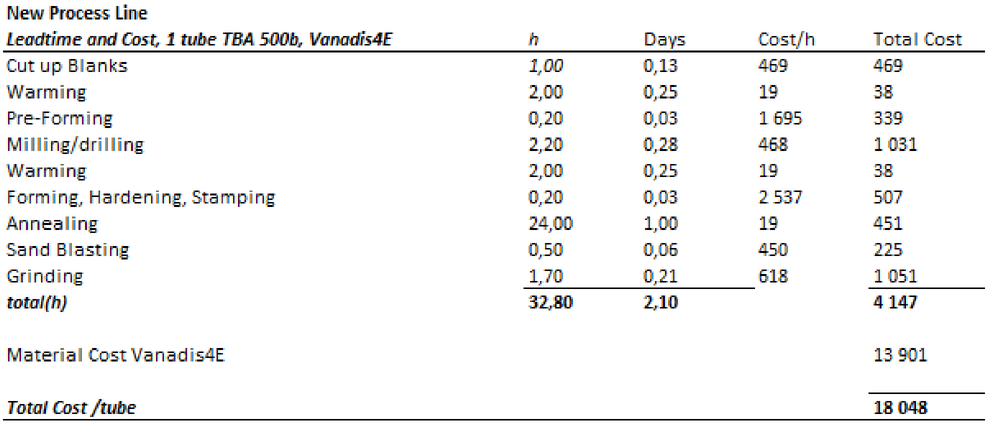


New Process Line

Leadtime and Cost, 1 tube TBA 500b, Caldie	*h*	Days	Cost/h	Total Cost
Cut up Blanks	*1,00*	0,13	469	469
Warming	2,00	0,25	19	38
Pre-Forming	0,20	0,03	1 695	339
Milling/drilling	2,20	0,28	468	1 031
Warming	2,00	0,25	19	38
Forming, Hardening, Stamping	0,20	0,03	2 537	507
Annealing	24,00	1,00	19	451
Sand Blasting	0,50	0,06	450	225
Grinding	8,50	1,06	618	5 253
total(h)	**39,60**	**2,95**		**8 349**
Material Cost Caldie				4 706
Total Cost /tube				**13 055** ←

[Appendix A,B,C]

Vanadis 4 Extra



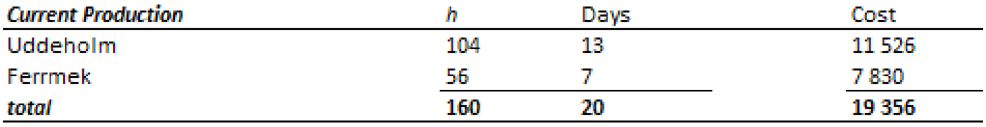
New Process Line

Leadtime and Cost, 1 tube TBA 500b, Vanadis4E	*h*	Days	Cost/h	Total Cost
Cut up Blanks	*1,00*	0,13	469	469
Warming	2,00	0,25	19	38
Pre-Forming	0,20	0,03	1 695	339
Milling/drilling	2,20	0,28	468	1 031
Warming	2,00	0,25	19	38
Forming, Hardening, Stamping	0,20	0,03	2 537	507
Annealing	24,00	1,00	19	451
Sand Blasting	0,50	0,06	450	225
Grinding	1,70	0,21	618	1 051
total(h)	**32,80**	**2,10**		**4 147**
Material Cost Vanadis4E				13 901
Total Cost /tube				**18 048**

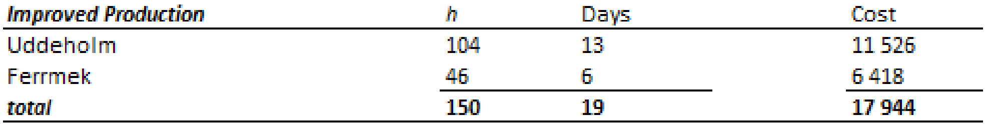
[Appendix A, B, C]

When hot formed and hardened in the same processing step, Vanadis 4 Extra shows to be the material with lowest deviations. However, since the cost of this material is three times the cost for Caldie it still is more cost efficient to use the Caldie steel.

The lead time for the Caldie steel is slightly higher than for Vanadis 4 extra.



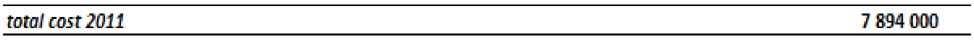
Current Production	*h*	Days	Cost
Uddeholm	104	13	11 526
Ferrmek	56	7	7 830
total	**160**	**20**	**19 356**



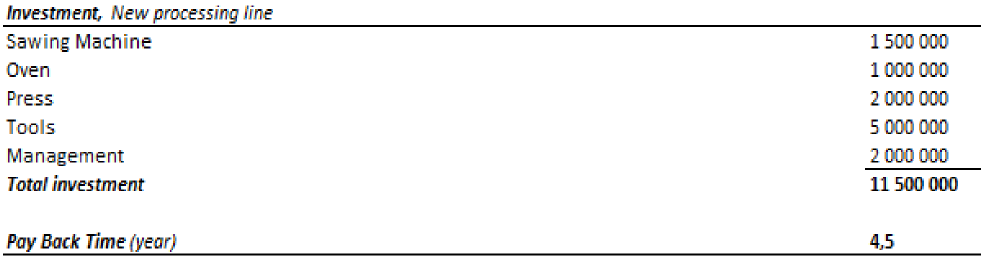
Improved Production	*h*	Days	Cost
Uddeholm	104	13	11 526
Ferrmek	46	6	6 418
total	**150**	**19**	**17 944**

[Appendix A, B, C]

When compared to the present method, the lead time is reduced by almost 90 % for both methods.



total cost 2011	**7 894 000**



Investment, *New processing line*	
Sawing Machine	1 500 000
Oven	1 000 000
Press	2 000 000
Tools	5 000 000
Management	2 000 000
Total investment	**11 500 000**
Pay Back Time *(year)*	**4,5**

And the payback of this investment if choosing Caldie would be 4, 5 years.

9 Recommendations and results

Current line
The cost of producing one tube of TBA 500b plates is today *~19 365kr* and the lead time is *~20 days*.

Improved Line
The cost to produce the same plate but with an improved production without any significant investments is estimated to *17 944 kr* per tube and the lead time is *19 days*.

Improved Line with Hot Forming
If investing in a hot forming line the cost for a tube is estimated to be *10 035 kr* for *Caldie* and *20 280 kr* for *Vanadis 4 Extra* and the lead time is *5* respectively *5.2 days*.

Improved Line with Hot Forming and Hardening in same step
Investing in a hot forming together with hardening line will estimate the cost for a tube to be:
13 055kr for *Caldie* and *18 048kr* for *Vanadis 4 Extra* and the lead time is *3* respectively *2.1 days*.

Recommendations
There is no doubt that improvements have to be made to the current production setup. The easiest improvements could be made first to get a better knowledge of the production line and to ensure a steady flowing production cycle before trying to implement any larger changes. Further analysis would then continually have to be made to follow up to make base for future decisions.

Later Ferrmek or Tetra Pak probably should look at a newer setup for their production line since it clearly shows that there are great potential of improvements to be made. And if the lead time is the most narrow sector the use of Vanadis 4 Extra together with hot forming and hardening in the same process could be the best alternative to go with since its only 90% of the current lead time.

However, its most likely enough to use the hot forming method since it’s the most cost efficient method with the shortest pay back method leading to the lowest risk, as well as the lead time being reduces by approximately 75 %.

10 References

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[4] **Tage, Christian.** *Production Manager, Sealing & Creasing Tetra Pak Lund.* [interv.] Andreas Eriksson. den 15 March 2012.

[5] **Larsson, Peter.** *Team Leader, Sealing & Creasing Tetra Pak Lund.* [interv.] Andreas Eriksson. den 24 April 2012.

[6] **Tetra Pak**. *Tetra Pak Global Site.* [Online] [Citat: den 3 May 2012.] http://www.tetrapak.com/se/about_tetra_pak/the_company/facts_and_figures/Pages/default.aspx.

11 Appendices

Appendix A – Excel sheet Grinding Analysis

Appendix B – Excel sheet Milling Analysis

Appendix C – Excel sheet Inventory Analysis

Appendix D – A study in hot Forming of High Strength Steel

Appendix A-1

Process

Orders 2011	Type	Amount Plates	Plates /tube	Amount Tubes	Length	Outer Ø Inner Ø	Reduction for male plates Outer(%)	Time Grinding Outer (min)	Time Change Plates Outer (min)	Time for Messurement, Kontroll, Tens-loosening... Outer (min)	Time Change Jig Outer (min)	Extra Outer Grinding 1000ml plates(%)	Extra Time for Outer Grinding 1000ml plates(%)	Grinding Outer Parallel Processes	Production Time Rate Outer Grinding	Reduction for Male plates Inner(%)	Time Grinding Inner (min)	Time Change Plates Inner (min)	Time for Messurement, Kontroll, Tens-loosening... Inner (min)	Time Change Jig Inner (min)	Grinding Inner Parallel Processes	Production Time Rate Inner Grinding (min)	Produktion Rate Grinding (min)
TT3 1000 CC	Female 2935152	32	4	8	264	312		163,90	10,00	12,00	18,00	163,90	100%	2	185,90		156,44	24,00	23,00	30	1	203,44	203,44
	Male 2935153	32		8		272	20%	131,12				131,12	100%		153,12	0%	156,44					203,44	203,44
TBA 200 B	Female 2591612	56	7	8	213	311,43		131,99	17,50	12,00	18,00	0,00	0%	2	95,50		125,96	42,00	23,00	30	2	95,48	95,50
	Male 2591613	56		8		271,43	20%	105,60				0,00	0%		82,30	0%	125,96					95,48	95,48
TBA 200 S	Female 2865115	60	6	10	173	330,44		113,75	15,00	12,00	18,00	0,00	0%	2	83,88		109,47	36,00	23,00	30	2	84,23	84,23
	Male 2865116	60		10		290,44	20%	91,00				0,00	0%		72,50	0%	109,47					84,23	84,23
TBA 200 B	Female 2591612	56	7	8	213	311,43		131,99	17,50	12,00	18,00	0,00	0%	2	95,50		125,96	42,00	23,00	30	2	95,48	95,50
	Male 2591613	56		8		271,43	20%	105,60				0,00	0%		82,30	0%	125,96					95,48	95,48
TBA 500 B	Female 79601	6	6	1	321	318,36		203,35	15,00	12,00	18,00	0,00	0%	2	128,67		194,67	36,00	23,00	30	2	126,83	128,67
				0		278,36	20%	162,68				0,00	0%		108,34	0%	194,67					126,83	126,83
TT 200 Mini	Female 2865193	72	8	9	179	331,1		117,93	20,00	12,00	18,00	0,00	0%	2	90,97		113,52	48,00	23,00	30	2	92,26	92,26
	Male 2865194	72		9		291,1	20%	94,34				0,00	0%		79,17	0%	113,52					92,26	92,26
TPA 200 SQ	Female 2987799	133	7	19	173	356,18		122,61	17,50	12,00	18,00	0,00	0%	2	90,81		119,17	42,00	23,00	30	2	92,08	92,08
	Male 2987800 , 298780	140		20		316,18	20%	98,09				0,00	0%		78,54	0%	119,17					92,08	92,08
TBA 200 S	Female 2865115	60	6	10	173	330,44		113,75	15,00	12,00	18,00	0,00	0%	2	83,88		109,47	36,00	23,00	30	2	84,23	84,23
	Male 2865116	60		10		290,44	20%	91,00				0,00	0%		72,50	0%	109,47					84,23	84,23
TBA 1000 SQ	Female 2883568	24	4	6	291	362,67		210,00	10,00	12,00	18,00	210,00	100%	2	232,00		204,57	24,00	23,00	30	1	251,57	251,57
	Male 2883568	24		6		322,67	20%	168,00				168,00	100%		190,00	0%	204,57					251,57	251,57
TBA 1000 B	Female 79189	24	4	6	321	312		199,29	10,00	12,00	18,00	199,29	100%	2	221,29		190,22	24,00	23,00	30	1	237,22	237,22
	Male 79190	24		6		272	20%	159,43				159,43	100%		181,43	0%	190,22					237,22	237,22
TBA 250 B	Female 2591614	48	6	8	213	311,34		131,96	15,00	12,00	18,00	0,00	0%	2	92,98		125,91	36,00	23,00	30	2	92,46	92,98
	Male 2591615	48		8		271,34	20%	105,57				0,00	0%		79,78	0%	125,91					92,46	92,46
TBA 250 S	Female 2883940	48	6	8	187	352,72		131,25	15,00	12,00	18,00	0,00	0%	2	92,62		127,40	36,00	23,00	30	2	93,20	93,20
	Male 2883941	48		8		312,72	20%	105,00				0,00	0%		79,50	0%	127,40					93,20	93,20
TBA 1000 S	Female 79193	12	4	3	304	343,83		207,99	10,00	12,00	18,00	207,99	100%	2	229,99		201,23	24,00	23,00	30	1	248,23	248,23
	Male 79194	16		4		303,83	20%	166,39				166,39	100%		188,39	0%	201,23					248,23	248,23

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TBA 125 S	Female 2883824	88	8	11	161	330,24		105,80	20,00	12,00	18,00	0,00	0%	2	84,90		101,80	48,00	23,00	30	2	86,40	86,40
	Male 2883825	88		11		290,24	20%	84,64				0,00	0%		74,32	0%	101,80					86,40	86,40
TBA 1000 B	Female 79189	24	4	6	321	312		199,29	10,00	12,00	18,00	199,29	100%	2	221,29		190,22	24,00	23,00	30	1	237,22	237,22
				0		272	20%	159,43				159,43	100%		181,43	0%	190,22					237,22	237,22
TBA 1000 S	Female 79193	24	4	6	304	343,83		207,99	10,00	12,00	18,00	207,99	100%	2	229,99		201,23	24,00	23,00	30	1	248,23	248,23
				0		303,83	20%	166,39				166,39	100%		188,39	0%	201,23					248,23	248,23
TPA 1000 SQ	Female 2935181	52	4	13	259	388,4		200,17	10,00	12,00	18,00	200,17	100%	2	222,17		196,59	24,00	23,00	30	1	243,59	243,59
				0		348,4	20%	160,13				160,13	100%		182,13	0%	196,59					243,59	243,59
TGA 1000 SQ Octagonal	Female 3146391-2	24	4	6	269	375,38		200,93	10,00	12,00	18,00	200,93	100%	2	222,93		196,55	24,00	23,00	30	1	243,55	243,55
	Male 3146391-3	2		1		335,38	20%	160,74				160,74	100%		182,74	0%	196,55					243,55	243,55
TGA 1000 SQ Octagonal	Female 3146392-2	24	4	6	269	375,38		200,93	10,00	12,00	18,00	200,93	100%	2	222,93		196,55	24,00	23,00	30	1	243,55	243,55
	Male 3146392-3	2		1		335,38	20%	160,74				160,74	100%		182,74	0%	196,55					243,55	243,55
TGA 1000 SQ Octagonal	Female 3146393-2	24	4	6	269	375,38		200,93	10,00	12,00	18,00	200,93	100%	2	222,93		196,55	24,00	23,00	30	1	243,55	243,55
	Male 3146393-3	2		1		335,38	20%	160,74				160,74	100%		182,74	0%	196,55					243,55	243,55
TGA 1000 SQ Octagonal	Female 3146394-2	24	4	6	269	375,38		200,93	10,00	12,00	18,00	200,93	100%	2	222,93		196,55	24,00	23,00	30	1	243,55	243,55
	Male 3146394-3	2		1		335,38	20%	160,74				160,74	100%		182,74	0%	196,55					243,55	243,55
TBA 80 S	Female 2591182	99	9	11	145	324,73		93,69	22,50	12,00	18,00	0,00	0%	2	81,35		89,95	54,00	23,00	30	2	83,47	83,47
	Male 2591183	99		11		284,73	20%	74,95				0,00	0%		71,98	0%	89,95					83,47	83,47
TBA 300 S	Female 2884005	48	6	8	213	336,91		142,79	15,00	12,00	18,00	0,00	0%	2	98,40		137,78	36,00	23,00	30	2	98,39	98,40
				0		296,91	20%	114,24				0,00	0%		84,12	0%	137,78					98,39	98,39
TBA 1000 S	Female 79193	24	4	6	304	343,83		207,99	10,00	12,00	18,00	207,99	100%	2	229,99		201,23	24,00	23,00	30	1	248,23	248,23
	Male 79194	24		6		303,83	20%	166,39				166,39	100%		188,39	0%	201,23					248,23	248,23
TBA 125 S	Female 2883824	88	8	11	161	330,24		105,80	20,00	12,00	18,00	0,00	0%	2	84,90		101,80	48,00	23,00	30	2	86,40	86,40
	Male 2883825	88		11		290,24	20%	84,64				0,00	0%		74,32	0%	101,80					86,40	86,40
TT/3 500 MIDI	Female 2865283	54	6	9	213	382,03		161,92	15,00	12,00	18,00	0,00	0%	2	107,96		158,72	36,00	23,00	30	2	108,86	108,86
	Male 2865284	54		9		342,03	20%	129,53				0,00	0%		91,77	0%	158,72					108,86	108,86
TT/3 330 MIDI	Female 2865277	56	8	7	213	382,03		161,92	20,00	12,00	18,00	0,00	0%	2	112,96		158,72	48,00	23,00	30	2	114,86	114,86
	Male 2865278	56		7		342,03	20%	129,53				0,00	0%		96,77	0%	158,72					114,86	114,86
TBA 1000 S	Female 79193	12	4	3	304	343,83		207,99	10,00	12,00	18,00	207,99	100%	2	229,99		201,23	24,00	23,00	30	1	248,23	248,23
	Male 79194	16		4		303,83	20%	166,39				166,39	100%		188,39	0%	201,23					248,23	248,23
TBA 250 S	Female 2883940	48	6	8	187	352,72		131,25	15,00	12,00	18,00	0,00	0%	2	92,62		127,40	36,00	23,00	30	2	93,20	93,20
	Male 2883941	48		8		312,72	20%	105,00				0,00	0%		79,50	0%	127,40					93,20	93,20
TPA 500 SQ(cansled)	Female 3189771																						
	Male 3189772 / 2591187																						
TBA 200 S	Female 2865115	36	6	6	173	330,44		113,75	15,00	12,00	18,00	0,00	0%	2	83,88		109,47	36,00	23,00	30	2	84,23	84,23
	Male 2865116	42		7		290,44	20%	91,00				0,00	0%		72,50	0%	109,47					84,23	84,23
TT3 1000 B	Female 2935152	28	4	7	264	312		163,90	10,00	12,00	18,00	163,90	100%	2	185,90		156,44	24,00	23,00	30	1	203,44	203,44
	Male 2935153	28		7		272	20%	131,12				131,12	100%		153,12	0%	156,44					203,44	203,44
TBA 1000 MID	Female 3120165	24	4	6	315	324,48		203,38	10,00	12,00	18,00	203,38	100%	2	225,38		195,23	24,00	23,00	30	1	242,23	242,23
	Male 3120515	24		6		284,48	20%	162,71				162,71	100%		184,71	0%	195,23					242,23	242,23
TBA 1000 MID	Female 3120165-0302	8	4	2	315	324,48		203,38	10,00	12,00	18,00	203,38	100%	2	225,38		195,23	24,00	23,00	30	1	242,23	242,23
	Male 3120515-0302	8		2		284,48	20%	162,71				162,71	100%		184,71	0%	195,23					242,23	242,23
TBA 1000 MID	Female 3120166	24	4	6	315	324,48		203,38	10,00	12,00	18,00	203,38	100%	2	225,38		195,23	24,00	23,00	30	1	242,23	242,23
	Male 3120164	24		6		284,48	20%	162,71				162,71	100%		184,71	0%	195,23					242,23	242,23
TBA 1000 MID	Female 3120166-0302	8	4	2	315	324,48		203,38	10,00	12,00	18,00	203,38	100%	2	225,38		195,23	24,00	23,00	30	1	242,23	242,23
	Male 3120164-0302	8		2		284,48	20%	162,71				162,71	100%		184,71	0%	195,23					242,23	242,23
TBA 500 B(Cansled)	Female 79601																						
	Male 79963																						
TPA 250 SQ	Female 2987796	114	6	19	173	352,99		121,51	15,00	12,00	18,00	0,00	0%	2	87,76		117,97	36,00	23,00	30	2	88,48	88,48
	Male 2987797/2987798	132		22		312,99	20%	97,21				0,00	0%		75,61	0%	117,97					88,48	88,48
TBA 200 S	Female 2865115	36	6	6	173	330,44		113,75	15,00	12,00	18,00	0,00	0%	2	83,88		109,47	36,00	23,00	30	2	84,23	84,23
	Male 2865116	41		7		290,44	20%	91,00				0,00	0%		72,50	0%	109,47					84,23	84,23
		3046	200	514	8929	23680	7	10866	500	444	666	6454	36	74	10548	0	11662	1200	851	1110	56	12195	12197

Appendix A-2

Possible Waiting Time Between Orders/Processes									Possible Savings Between Orders							Costs													Time Processes				
Tubes/ Day	Waiting Time/ Day if only start processes that will finish (h)	Total Waiting Time (- Last day) /Order(h)	Time Last Day if Waiting to Start New Order Until the Next Day /Order(h)	Total Waiting Time(h)	Total time /Order (h)	Total Days /Order	Total Days	Prod. Order no.	Saved Waiting Time by Starting new Order Same Day(h)	Time for Stopping production between days(h)	Saved Waiting Time by Stopping Machine between days(h)	Total time Order (h)	Total Days Order	minimal theoretical time (h)	SMED (max 10min)	Volume	Total Volume	Cost Tubes	Cost one Tube	Cost Tubes /Plate	Allocation factor	Cost Grinding	Cost Grinding /Plate	Cost Milling /Plate	Cost Hardening /Plate	Total Cost Ferrmek	Total Cost TP Creasing	Total Cost /Order	Time hardening (h)	Theoretical Time Milling (h)	Theoretical Time Grinding (h)	Total Theoretical time (h)	Total Theoretical time (days)
2,4	2,0	8,0	5,4	13,4	41,0	5,1	6,0	1132469	5,4	0,0	8,0	27,6	3,5	21,9	23,4	0,0048	0,0387	74217,9	9277,2	2319,3	0,023	42818,5	1338,1	316,9	366,7	2021,7	4341,0	277823,9	40,0	15,1	27,6	82,7	10,3
2,4	2,0	8,0	5,4	13,4	41,0	5,1	6,0	1132470	5,4	0,0	8,0	27,6	3,5	20,9	22,4		0,0387	74217,9	9277,2	2319,3	0,023	42818,5	1338,1	443,8	366,7	2148,6	4467,9		40,0	21,1	27,6	88,7	11,1
5,0	0,0	0,0	3,2	3,2	16,4	2,1	3,0	1134384	3,2	0,0	0,0	13,2	1,7	8,4	9,9	0,0039	0,0312	59763,5	7470,4	1067,2	0,011	20555,1	367,1	152,9	366,7	886,6	1953,8	218826,4	40,0	12,7	13,2	66,0	8,2
5,0	0,0	0,0	3,2	3,2	16,4	2,1	3,0	1134383	3,2	0,0	0,0	13,2	1,7	8,4	9,9		0,0312	59763,5	7470,4	1067,2	0,011	20552,2	367,0	211,3	366,7	944,9	2012,2		40,0	17,6	13,2	70,8	8,9
5,7	0,4	0,8	2,0	2,8	17,3	2,2	3,0	1134387	2,0	0,0	0,8	14,6	1,8	9,1	11,0	0,0034	0,0337	64633,2	6463,3	1077,2	0,012	22608,8	376,8	159,5	366,7	903,0	1980,2	237627,3	40,0	14,2	14,6	68,8	8,6
5,7	0,4	0,8	2,0	2,8	17,3	2,2	3,0	1134388	2,0	0,0	0,8	14,6	1,8	9,1	11,0		0,0337	64633,2	6463,3	1077,2	0,012	22608,8	376,8	218,2	366,7	961,7	2038,9		40,0	19,4	14,6	74,0	9,3
5,0	0,0	0,0	3,2	3,2	16,4	2,1	3,0	1136483	3,2	0,0	0,0	13,2	1,7	8,4	9,9	0,0039	0,0312	59763,5	7470,4	1067,2	0,011	20555,1	367,1	152,9	366,7	886,6	1953,8	218826,4	40,0	12,7	13,2	66,0	8,2
5,0	0,0	0,0	3,2	3,2	16,4	2,1	3,0	1136484	3,2	0,0	0,0	13,2	1,7	8,4	9,9		0,0312	59763,5	7470,4	1067,2	0,011	20552,2	367,0	211,3	366,7	944,9	2012,2		40,0	17,6	13,2	70,8	8,9
3,7	0,6	0,2	5,8	6,0	8,6	1,1	2,0	1136668	5,8	0,0	0,2	2,7	0,3	1,6	2,0	0,0060	0,0060	11526,0	11526,0	1921,0	0,002	4117,7	686,3	252,0	366,7	1305,0	3226,0	19355,8	40,0	2,2	2,7	44,9	5,6
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	0,0	0,0	0,2		0,0000	0,0	0,0	0,0	0,000	0,0	0,0	0,0	366,7	0,0	0,0		0,0	0,0	0,0	0,0	0,0
5,2	1,2	2,2	2,2	4,3	18,6	2,3	3,0	1136674	2,2	0,0	2,2	14,3	1,8	8,5	10,2	0,0035	0,0315	60315,3	6701,7	837,7	0,012	22225,4	308,7	122,9	366,7	798,2	1635,9	235576,3	40,0	13,1	14,3	67,5	8,4
5,2	1,2	2,2	2,2	4,3	18,6	2,3	3,0	1136673	2,2	0,0	2,2	14,3	1,8	8,5	10,2		0,0315	60315,3	6701,7	837,7	0,012	22225,4	308,7	168,5	366,7	843,9	1681,6		40,0	18,0	14,3	72,3	9,0
5,2	1,2	4,6	2,8	7,3	37,0	4,6	5,0	1136679	2,8	0,0	4,6	29,6	3,7	18,9	22,2	0,0037	0,0694	132985,3	6999,2	999,9	0,024	45978,6	345,7	144,6	366,7	856,9	1856,8	506916,7	40,0	28,5	29,6	98,2	12,3
5,2	1,2	4,8	1,2	6,0	37,2	4,6	5,0	1136720, 1136721	1,2	0,0	4,8	31,2	3,9	19,9	23,4		0,0731	139984,5	6999,2	999,9	0,025	48351,4	345,4	198,8	366,7	910,9	1910,7		40,0	41,3	31,2	112,5	14,1
5,7	0,4	0,8	2,0	2,8	17,3	2,2	3,0	1136724	2,0	0,0	0,8	14,6	1,8	9,1	11,0	0,0034	0,0337	64633,2	6463,3	1077,2	0,012	22608,8	376,8	159,5	366,7	903,0	1980,2	237627,3	40,0	14,2	14,6	68,8	8,6
5,7	0,4	0,8	2,0	2,8	17,3	2,2	3,0	1136725	2,0	0,0	0,8	14,6	1,8	9,1	11,0		0,0337	64633,2	6463,3	1077,2	0,012	22608,8	376,8	218,2	366,7	961,7	2038,9		40,0	19,4	14,6	74,0	9,3
1,9	0,4	2,4	6,7	9,1	34,8	4,3	5,0	1136755	6,7	0,0	2,4	25,6	3,2	21,0	22,2	0,0063	0,0376	72003,3	12000,5	3000,1	0,021	39789,7	1657,9	388,3	366,7	2412,9	5413,0	259825,9	40,0	13,8	25,6	79,5	9,9
1,9	0,4	2,4	6,7	9,1	34,8	4,3	5,0	1136756	6,7	0,0	2,4	25,6	3,2	20,5	21,6		0,0376	72003,3	12000,5	3000,1	0,021	39789,7	1657,9	550,9	366,7	2575,5	5575,6		40,0	19,6	25,6	85,3	10,7
2,0	0,0	0,0	0,0	0,0	24,2	3,0	4,0	1137391	0,0	0,0	0,0	24,2	3,0	19,9	21,1	0,0059	0,0353	67681,7	11280,3	2820,1	0,020	37577,2	1565,7	371,7	366,7	2304,1	5124,2	245961,2	40,0	13,2	24,2	77,5	9,7
2,0	0,0	0,0	0,0	0,0	24,2	3,0	4,0	1137392	0,0	0,0	0,0	24,2	3,0	19,0	20,2		0,0353	67681,7	11280,3	2820,1	0,020	37577,2	1565,7	526,0	366,7	2458,4	5278,5		40,0	18,7	24,2	83,0	10,4
5,2	1,2	1,9	3,7	5,6	18,5	2,3	3,0	1136738	3,7	0,0	1,9	12,9	1,6	8,4	9,9	0,0039	0,0312	59745,0	7468,1	1244,7	0,010	19947,4	415,6	178,3	366,7	960,6	2205,2	211703,5	40,0	12,7	12,9	65,6	8,2
5,2	1,2	1,9	3,7	5,6	18,4	2,3	3,0	1136739	3,7	0,0	1,9	12,8	1,6	8,4	9,9		0,0312	59745,0	7468,1	1244,7	0,010	19872,0	414,0	246,4	366,7	1027,1	2271,8		40,0	17,6	12,8	70,4	8,8
5,2	1,2	1,9	3,7	5,6	18,5	2,3	3,0	1136732	3,7	0,0	1,9	12,9	1,6	8,5	10,0	0,0039	0,0313	59902,2	7487,8	1248,0	0,011	19979,7	416,2	177,6	366,7	960,5	2208,5	212012,2	40,0	12,7	12,9	65,5	8,2
5,2	1,2	1,9	3,7	5,6	18,5	2,3	3,0	1136733	3,7	0,0	1,9	12,9	1,6	8,5	10,0		0,0313	59902,2	7487,8	1248,0	0,011	19979,7	416,2	245,3	366,7	1028,2	2276,2		40,0	17,5	12,9	70,4	8,8
1,9	0,4	1,2	3,3	4,5	17,4	2,2	3,0	1138442	3,3	0,0	1,2	12,9	1,6	10,4	11,1	0,0062	0,0186	35542,2	11847,4	2961,8	0,011	20015,2	1667,9	385,2	366,7	2419,8	5381,7	150686,4	40,0	6,9	12,9	59,8	7,5
1,9	0,4	1,6	7,0	8,6	25,6	3,2	4,0	1138443	7,0	0,0	1,6	17,0	2,1	13,4	14,2		0,0247	47389,6	11847,4	2961,8	0,014	26397,0	1649,8	546,2	366,7	2562,7	5524,6		40,0	13,0	17,0	70,0	8,7

Appendix A-3

5,6	0,6	1,3	0,3	1,6	17,9	2,2	3,0	1138437	0,3	0,0	1,3	16,3	2,0	9,3	11,3	0,0031	0,0345	66122,4	6011,1	751,4	0,013	25337,5	287,9	113,5	366,7	768,1	1519,5	267426,6	40,0	14,8	16,3	71,2	8,9
5,6	0,6	1,3	0,3	1,6	17,9	2,2	3,0	1138438	0,3	0,0	1,3	16,3	2,0	9,3	11,3		0,0345	66122,4	6011,1	751,4	0,013	25337,5	287,9	154,4	366,7	809,0	1560,4		40,0	20,2	16,3	76,5	9,6
2,0	0,0	0,0	0,0	0,0	24,2	3,0	4,0	1140831	0,0	0,0	0,0	24,2	3,0	19,9	21,1	0,0059	0,0353	67681,7	11280,3	2820,1	0,020	37577,2	1565,7	371,7	366,7	2304,1	5124,2	122980,6	40,0	13,2	24,2	77,5	9,7
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	0,0	0,0	0,2		0,0000	0,0	0,0	0,0	0,000	0,0	0,0	0,0	366,7	0,0	0,0		0,0	0,0	0,0	0,0	0,0
1,9	0,4	2,4	6,6	9,0	34,3	4,3	5,0	1140832	6,6	0,0	2,4	25,3	3,2	20,8	22,0	0,0062	0,0371	71084,3	11847,4	2961,8	0,021	39254,7	1635,6	385,2	366,7	2387,5	5349,3	128384,1	40,0	13,7	25,3	79,0	9,9
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	0,0	0,0	0,2		0,0000	0,0	0,0	0,0	0,000	0,0	0,0	0,0	366,7	0,0	0,0		0,0	0,0	0,0	0,0	0,0
2,0	0,0	0,0	4,1	4,1	57,4	7,2	8,0	1140833	4,1	0,0	0,0	53,3	6,7	43,4	45,7	0,0060	0,0779	149277,7	11482,9	2870,7	0,043	82715,6	1590,7	373,1	366,7	2330,5	5201,2	270461,4	40,0	28,8	53,3	122,1	15,3
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	0,0	0,0	0,2		0,0000	0,0	0,0	0,0	0,000	0,0	0,0	0,0	366,7	0,0	0,0		0,0	0,0	0,0	0,0	0,0
2,0	0,0	0,0	0,0	0,0	24,9	3,1	4,0	1141753	0,0	0,0	0,0	24,9	3,1	20,1	21,3	0,0060	0,0360	69028,5	11504,8	2876,2	0,020	38559,1	1606,6	374,3	366,7	2347,6	5223,8	135817,9	40,0	13,3	24,9	78,2	9,8
2,0	0,0	0,0	6,1	6,1	8,6	1,1	2,0	1141753	6,1	0,0	0,0	2,5	0,3	1,6	1,9		0,0030	5752,4	11504,8	2876,2	0,002	3941,7	1970,9	529,8	366,7	2867,4	5743,6		40,0	1,6	2,5	44,1	5,5
2,0	0,0	0,0	0,0	0,0	24,9	3,1	4,0	1141754	0,0	0,0	0,0	24,9	3,1	20,1	21,3	0,0060	0,0360	69028,5	11504,8	2876,2	0,020	38559,1	1606,6	374,3	366,7	2347,6	5223,8	135817,9	40,0	13,3	24,9	78,2	9,8
2,0	0,0	0,0	6,1	6,1	8,6	1,1	2,0	1141754	6,1	0,0	0,0	2,5	0,3	1,6	1,9		0,0030	5752,4	11504,8	2876,2	0,002	3941,7	1970,9	529,8	366,7	2867,4	5743,6		40,0	1,6	2,5	44,1	5,5
2,0	0,0	0,0	0,0	0,0	24,9	3,1	4,0	1141755	0,0	0,0	0,0	24,9	3,1	20,1	21,3	0,0060	0,0360	69028,5	11504,8	2876,2	0,020	38559,1	1606,6	374,3	366,7	2347,6	5223,8	135817,9	40,0	13,3	24,9	78,2	9,8
2,0	0,0	0,0	6,1	6,1	8,6	1,1	2,0	1141755	6,1	0,0	0,0	2,5	0,3	1,6	1,9		0,0030	5752,4	11504,8	2876,2	0,002	3941,7	1970,9	529,8	366,7	2867,4	5743,6		40,0	1,6	2,5	44,1	5,5
2,0	0,0	0,0	0,0	0,0	24,9	3,1	4,0	1141820	0,0	0,0	0,0	24,9	3,1	20,1	21,3	0,0060	0,0360	69028,5	11504,8	2876,2	0,020	38559,1	1606,6	374,3	366,7	2347,6	5223,8	135817,9	40,0	13,3	24,9	78,2	9,8
2,0	0,0	0,0	6,1	6,1	8,6	1,1	2,0	1141820	6,1	0,0	0,0	2,5	0,3	1,6	1,9		0,0030	5752,4	11504,8	2876,2	0,002	3941,7	1970,9	529,8	366,7	2867,4	5743,6		40,0	1,6	2,5	44,1	5,5
5,8	0,3	0,7	0,8	1,5	17,3	2,2	3,0	1144330	0,8	0,0	0,7	15,8	2,0	8,2	10,2	0,0028	0,0305	58493,5	5317,6	590,8	0,013	24525,0	247,7	92,5	366,7	706,9	1297,8	256961,4	40,0	13,6	15,8	69,4	8,7
5,8	0,3	0,7	0,8	1,5	17,3	2,2	3,0	1144331	0,8	0,0	0,7	15,8	2,0	8,2	10,2		0,0305	58493,5	5317,6	590,8	0,013	24525,0	247,7	124,8	366,7	739,2	1330,0		40,0	18,3	15,8	74,1	9,3
4,9	0,2	0,4	3,0	3,4	17,0	2,1	3,0	1141677	3,0	0,0	0,4	13,7	1,7	9,2	10,7	0,0042	0,0339	64988,7	8123,6	1353,9	0,011	21203,5	441,7	189,5	366,7	997,9	2351,8	112888,6	40,0	13,5	13,7	67,2	8,4
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	0,0	0,0	0,2		0,0000	0,0	0,0	0,0	0,000	0,0	0,0	0,0	366,7	0,0	0,0		0,0	0,0	0,0	0,0	0,0
1,9	0,4	2,4	6,6	9,0	34,3	4,3	5,0	1141681	6,6	0,0	2,4	25,3	3,2	20,8	22,0	0,0062	0,0371	71084,3	11847,4	2961,8	0,021	39254,7	1635,6	385,2	366,7	2387,5	5349,3	256768,2	40,0	13,7	25,3	79,0	9,9
1,9	0,4	2,4	6,6	9,0	34,3	4,3	5,0	1141683	6,6	0,0	2,4	25,3	3,2	20,1	21,3		0,0371	71084,3	11847,4	2961,8	0,021	39254,7	1635,6	546,2	366,7	2548,5	5510,4		40,0	19,5	25,3	84,8	10,6
5,6	0,6	1,3	0,3	1,6	17,9	2,2	3,0	1144360	0,3	0,0	1,3	16,3	2,0	9,3	11,3	0,0031	0,0345	66122,4	6011,1	751,4	0,013	25337,5	287,9	113,5	366,7	768,1	1519,5	267426,6	40,0	14,8	16,3	71,2	8,9
5,6	0,6	1,3	0,3	1,6	17,9	2,2	3,0	1144361	0,3	0,0	1,3	16,3	2,0	9,3	11,3		0,0345	66122,4	6011,1	751,4	0,013	25337,5	287,9	154,4	366,7	809,0	1560,4		40,0	20,2	16,3	76,5	9,6
4,4	1,1	2,5	7,6	10,1	26,9	3,4	4,0	1145858	7,6	0,0	2,5	16,8	2,1	11,9	13,6	0,0048	0,0436	83521,6	9280,2	1546,7	0,014	26115,2	483,6	209,2	366,7	1059,5	2606,2	281472,6	40,0	16,8	16,8	73,6	9,2
4,4	1,1	2,5	7,6	10,1	26,9	3,4	4,0	1145859	7,6	0,0	2,5	16,8	2,1	11,9	13,6		0,0436	83521,6	9280,2	1546,7	0,014	26115,2	483,6	292,8	366,7	1143,1	2689,8		40,0	23,5	16,8	80,3	10,0
4,2	1,5	2,6	2,7	5,3	19,2	2,4	3,0	1145856	2,7	0,0	2,6	13,9	1,7	9,3	10,6	0,0048	0,0339	64961,2	9280,2	1160,0	0,011	21556,5	384,9	156,9	366,7	908,5	2068,6	231679,1	40,0	13,0	13,9	66,9	8,4
4,2	1,5	2,6	2,7	5,3	19,2	2,4	3,0	1145857	2,7	0,0	2,6	13,9	1,7	9,3	10,6		0,0339	64961,2	9280,2	1160,0	0,011	21556,5	384,9	219,6	366,7	971,2	2131,2		40,0	18,3	13,9	72,2	9,0
1,9	0,4	1,2	3,3	4,5	17,4	2,2	3,0	1138442	3,3	0,0	1,2	12,9	1,6	10,4	11,1	0,0062	0,0186	35542,2	11847,4	2961,8	0,011	20015,2	1667,9	385,2	366,7	2419,8	5381,7	150686,4	40,0	6,9	12,9	59,8	7,5
1,9	0,4	1,6	7,0	8,6	25,6	3,2	4,0	1138443	7,0	0,0	1,6	17,0	2,1	13,4	14,2		0,0247	47389,6	11847,4	2961,8	0,014	26397,0	1649,8	546,2	366,7	2562,7	5524,6		40,0	13,0	17,0	70,0	8,7
5,2	1,2	1,9	3,7	5,6	18,5	2,3	3,0	1136732	3,7	0,0	1,9	12,9	1,6	8,5	10,0	0,0039	0,0313	59902,2	7487,8	1248,0	0,011	19979,7	416,2	177,6	366,7	960,5	2208,5	212012,2	40,0	12,7	12,9	65,5	8,2
5,2	1,2	1,9	3,7	5,6	18,5	2,3	3,0	1136733	3,7	0,0	1,9	12,9	1,6	8,5	10,0		0,0313	59902,2	7487,8	1248,0	0,011	19979,7	416,2	245,3	366,7	1028,2	2276,2		40,0	17,5	12,9	70,4	8,8
								1152159																				0,0					
								1152340 / 1152517																									
5,7	0,4	0,5	7,6	8,1	17,0	2,1	3,0	1149837	7,6	0,0	0,5	9,0	1,1	5,5	6,6	0,0034	0,0202	38779,9	6463,3	1077,2	0,007	13903,8	386,2	159,5	366,7	912,4	1989,6	155191,2	40,0	8,5	9,0	57,5	7,2
5,7	0,4	0,6	6,2	6,7	17,0	2,1	3,0	1149838	6,2	0,0	0,6	10,3	1,3	6,4	7,7		0,0236	45243,3	6463,3	1077,2	0,008	15963,7	380,1	218,2	366,7	965,0	2042,2		40,0	13,6	10,3	63,9	8,0
2,4	2,0	7,0	0,7	7,7	31,9	4,0	4,0	1152724	0,7	0,0	7,0	24,3	3,0	19,1	20,5	0,0048	0,0339	64940,7	9277,2	2319,3	0,020	37631,2	1344,0	316,9	366,7	2027,6	4346,9	243425,9	40,0	13,2	24,3	77,4	9,7
2,4	2,0	7,0	0,7	7,7	31,9	4,0	4,0	1152710	0,7	0,0	7,0	24,3	3,0	18,3	19,6		0,0339	64940,7	9277,2	2319,3	0,020	37631,2	1344,0	443,8	366,7	2154,5	4473,8		40,0	18,4	24,3	82,7	10,3
2,0	0,0	0,0	0,0	0,0	24,7	3,1	4,0	1152694	0,0	0,0	0,0	24,7	3,1	20,3	21,5	0,0060	0,0362	69255,2	11542,5	2885,6	0,020	38354,3	1598,1	378,1	366,7	2342,8	5228,5	250967,1	40,0	13,5	24,7	78,2	9,8
2,0	0,0	0,0	0,0	0,0	24,7	3,1	4,0	1152691	0,0	0,0	0,0	24,7	3,1	19,5	20,7		0,0362	69255,2	11542,5	2885,6	0,020	38354,3	1598,1	535,5	366,7	2500,3	5385,9		40,0	19,1	24,7	83,8	10,5
2,0	0,0	0,0	0,0	0,0	8,6	1,1	2,0	1152695	0,0	0,0	0,0	8,6	1,1	6,8	7,3	0,0060	0,0121	23085,1	11542,5	2885,6	0,007	13301,9	1662,7	378,1	366,7	2407,5	5293,1	84689,9	40,0	4,5	8,6	53,1	6,6
2,0	0,0	0,0	0,0	0,0	8,6	1,1	2,0	1152693	0,0	0,0	0,0	8,6	1,1	6,5	7,0		0,0121	23085,1	11542,5	2885,6	0,007	13301,9	1662,7	535,5	366,7	2565,0	5450,6		40,0	6,4	8,6	54,9	6,9
2,0	0,0	0,0	0,0	0,0	24,7	3,1	4,0	1152696	0,0	0,0	0,0	24,7	3,1	20,3	21,5	0,0060	0,0362	69255,2	11542,5	2885,6	0,020	38354,3	1598,1	378,1	366,7	2342,8	5228,5	250967,1	40,0	13,5	24,7	78,2	9,8
2,0	0,0	0,0	0,0	0,0	24,7	3,1	4,0	1152683	0,0	0,0	0,0	24,7	3,1	19,5	20,7		0,0362	69255,2	11542,5	2885,6	0,020	38354,3	1598,1	535,5	366,7	2500,3	5385,9		40,0	19,1	24,7	83,8	10,5
2,0	0,0	0,0	0,0	0,0	8,6	1,1	2,0	1152697	0,0	0,0	0,0	8,6	1,1	6,8	7,3	0,0060	0,0121	23085,1	11542,5	2885,6	0,007	13301,9	1662,7	378,1	366,7	2407,5	5293,1	84689,9	40,0	4,5	8,6	53,1	6,6
2,0	0,0	0,0	0,0	0,0	8,6	1,1	2,0	1152690	0,0	0,0	0,0	8,6	1,1	6,5	7,0		0,0121	23085,1	11542,5	2885,6	0,007	13301,9	1662,7	535,5	366,7	2565,0	5450,6		40,0	6,4	8,6	54,9	6,9
								1152752																				0,0					
								1152753																									
5,4	0,9	3,4	3,8	7,3	35,8	4,5	5,0	1153734	3,8	0,0	3,4	28,6	3,6	18,7	22,0	0,0036	0,0688	131723,4	6932,8	1155,5	0,023	44315,4	388,7	167,5	366,7	922,9	2078,4	511288,1	40,0	28,4	28,6	96,9	12,1
5,4	0,9	4,0	7,4	11,3	44,2	5,5	6,0	153735 / 115373	7,4	0,0	4,0	32,9	4,1	21,6	25,5		0,0796	152521,8	6932,8	1155,5	0,027	51055,8	386,8	230,3	366,7	983,7	2139,2		40,0	45,1	32,9	118,0	14,8
5,7	0,4	0,5	7,6	8,1	17,0	2,1	3,0	1153673	0,0	0,0	0,5	16,5	2,1	5,5	6,6	0,0034	0,0202	38779,9	6463,3	1077,2	0,013	25664,8	712,9	159,5	366,7	1239,1	2316,3	178357,0	40,0	8,5	16,5	65,1	8,1
5,7	0,4	0,5	6,4	7,0	17,1	2,1	3,0	1153674	0,0	0,0	0,5	16,5	2,1	6,2	7,5		0,0231	44166,0	6463,3	1077,2	0,013	25669,8	626,1	218,2	366,7	1211,0	2288,2		40,0	13,3	16,5	69,8	8,7
255	38	103	217	320	1532	191	245	79982843	203	0	103	1226	153	874	972	0	2	4278705	632937	132666	1,000	1901950											

Appendix B-1

Orders 2011	Hona/Hane	Amount Plates	Plates /tube	Amunt Tubes	Length	Outer Ø	Reduction for male plates Outer(%)	Change of Tube (min)	Milling (min)	Control/ measurment (min)	Production Rate Milling (h)	Total Time Order (h)	minimal theoretical time (h)	SMED (max 10min)	Allocation factor	Cost Milling	Cost Milling /Plate	time of actual	total of actual	total days of actual
TT3 1000 CC	Female 2935152	32	4	8	264	312		19,00	90,43	3,50	1,88	15,1	12,1	13,6	0,0146	10142,1	316,9	22,3	53,6	6,7
	Male 2935153	32		8			0%	19,00	135,64	3,50	2,64	21,1	18,1	19,6	0,0204	14202,8	443,8	31,3		
TBA 200 B	Female 2591612	56	7	8	213	311,43		19,00	72,82	3,50	1,59	12,7	9,7	11,2	0,0123	8561,3	152,9	18,9	44,9	5,6
	Male 2591613	56		8			0%	19,00	109,24	3,50	2,20	17,6	14,6	16,1	0,0170	11831,5	211,3	26,1		
TBA 200 S	Female 2865115	60	6	10	173	330,44		19,00	62,76	3,50	1,42	14,2	10,5	12,3	0,0137	9571,6	159,5	21,1	49,9	6,2
	Male 2865116	60		10			0%	19,00	94,14	3,50	1,94	19,4	15,7	17,5	0,0188	13094,4	218,2	28,8		
TBA 200 B	Female 2591612	56	7	8	213	311,43		19,00	72,82	3,50	1,59	12,7	9,7	11,2	0,0123	8561,3	152,9	18,9	44,9	5,6
	Male 2591613	56		8			0%	19,00	109,24	3,50	2,20	17,6	14,6	16,1	0,0170	11831,5	211,3	26,1		
TBA 500 B	Female 79601	6	6	1	321	318,36		19,00	112,19	3,50	2,24	2,2	1,9	2,2	0,0022	1512,1	252,0	3,3	3,3	0,4
				0			0%	19,00	168,29	3,50	3,18	0,0	0,0	0,2	0,0000	0,0	0,0	0,0		
TT 200 Mini	Female 2865193	72	8	9	179	331,1		19,00	65,07	3,50	1,46	13,1	9,8	11,4	0,0127	8847,5	122,9	19,5	46,2	5,8
	Male 2865194	72		9			0%	19,00	97,60	3,50	2,00	18,0	14,6	16,3	0,0174	12134,5	168,5	26,7		
TPA 200 SQ	Female 2987799	133	7	19	173	356,18		19,00	67,65	3,50	1,50	28,5	21,4	24,8	0,0276	19228,8	144,6	42,4	103,7	13,0
	Male 2987800 , 2987801	140		20			0%	19,00	101,47	3,50	2,07	41,3	33,8	37,3	0,0400	27835,3	198,8	61,3		
TBA 200 S	Female 2865115	60	6	10	173	330,44		19,00	62,76	3,50	1,42	14,2	10,5	12,3	0,0137	9571,6	159,5	21,1	49,9	6,2
	Male 2865116	60		10			0%	19,00	94,14	3,50	1,94	19,4	15,7	17,5	0,0188	13094,4	218,2	28,8		
TBA 1000 SQ	Female 2883568	24	4	6	291	362,67		19,00	115,86	3,50	2,31	13,8	11,6	12,8	0,0134	9319,9	388,3	20,5	49,7	6,2
	Male 2883568	24		6			0%	19,00	173,79	3,50	3,27	19,6	17,4	18,5	0,0190	13222,1	550,9	29,1		
TBA 1000 B	Female 79189	24	4	6	321	312		19,00	109,95	3,50	2,21	13,2	11,0	12,2	0,0128	8921,7	371,7	19,7	47,5	5,9
	Male 79190	24		6			0%	19,00	164,93	3,50	3,12	18,7	16,5	17,7	0,0181	12624,8	526,0	27,8		
TBA 250 B	Female 2591614	48	6	8	213	311,34		19,00	72,80	3,50	1,59	12,7	9,7	11,2	0,0123	8559,4	178,3	18,9	44,9	5,6
	Male 2591615	48		8			0%	19,00	109,21	3,50	2,20	17,6	14,6	16,1	0,0170	11828,7	246,4	26,1		
TBA 250 S	Female 2883940	48	6	8	187	352,72		19,00	72,41	3,50	1,58	12,7	9,7	11,2	0,0122	8524,2	177,6	18,8	44,7	5,6
	Male 2883941	48		8			0%	19,00	108,62	3,50	2,19	17,5	14,5	16,0	0,0169	11775,9	245,3	25,9		
TBA 1000 S	Female 79193	12	4	3	304	343,83		19,00	114,75	3,50	2,29	6,9	5,7	6,4	0,0066	4622,5	385,2	10,2	29,4	3,7
	Male 79194	16		4			0%	19,00	172,13	3,50	3,24	13,0	11,5	12,3	0,0125	8739,9	546,2	19,3		
TBA 125 S	Female 2883824	88	8	11	161	330,24		19,00	58,37	3,50	1,35	14,8	10,7	12,7	0,0143	9986,8	113,5	22,0	51,9	6,5
	Male 2883825	88		11			0%	19,00	87,56	3,50	1,83	20,2	16,1	18,1	0,0195	13590,9	154,4	29,9		
TBA 1000 B	Female 79189	24	4	6	321	312		19,00	109,95	3,50	2,21	13,2	11,0	12,2	0,0128	8921,7	371,7	19,7	19,7	2,5
				0			0%	19,00	164,93	3,50	3,12	0,0	0,0	0,2	0,0000	0,0	0,0	0,0		
TBA 1000 S	Female 79193	24	4	6	304	343,83		19,00	114,75	3,50	2,29	13,7	11,5	12,6	0,0133	9245,0	385,2	20,4	20,4	2,5
				0			0%	19,00	172,13	3,50	3,24	0,0	0,0	0,2	0,0000	0,0	0,0	0,0		

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TPA 1000 SQ	Female 2935181	52	4	13	259	388,4		19,00	110,44	3,50	2,22	28,8	23,9	26,3	0,0278	19401,5	373,1	42,7	42,7	5,3
				0			0%	19,00	165,66	3,50	3,14	0,0	0,0	0,2	0,0000	0,0	0,0	0,0		
TGA 1000 SQ Octagonal	Female 3146391-2	24	4	6	269	375,38		19,00	110,86	3,50	2,22	13,3	11,1	12,3	0,0129	8982,7	374,3	19,8	22,1	2,8
	Male 3146391-3	2		1			0%	19,00	166,28	3,50	3,15	1,6	1,4	1,6	0,0015	1059,7	529,8	2,3		
TGA 1000 SQ Octagonal	Female 3146392-2	24	4	6	269	375,38		19,00	110,86	3,50	2,22	13,3	11,1	12,3	0,0129	8982,7	374,3	19,8	22,1	2,8
	Male 3146392-3	2		1			0%	19,00	166,28	3,50	3,15	1,6	1,4	1,6	0,0015	1059,7	529,8	2,3		
TGA 1000 SQ Octagonal	Female 3146393-2	24	4	6	269	375,38		19,00	110,86	3,50	2,22	13,3	11,1	12,3	0,0129	8982,7	374,3	19,8	22,1	2,8
	Male 3146393-3	2		1			0%	19,00	166,28	3,50	3,15	1,6	1,4	1,6	0,0015	1059,7	529,8	2,3		
TGA 1000 SQ Octagonal	Female 3146394-2	24	4	6	269	375,38		19,00	110,86	3,50	2,22	13,3	11,1	12,3	0,0129	8982,7	374,3	19,8	22,1	2,8
	Male 3146394-3	2		1			0%	19,00	166,28	3,50	3,15	1,6	1,4	1,6	0,0015	1059,7	529,8	2,3		
TBA 80 S	Female 2591182	99	9	11	145	324,73		19,00	51,69	3,50	1,24	13,6	9,5	11,5	0,0131	9162,1	92,5	20,2	47,4	5,9
	Male 2591183	99		11			0%	19,00	77,54	3,50	1,67	18,3	14,2	16,2	0,0177	12353,9	124,8	27,2		
TBA 300 S	Female 2884005	48	6	8	213	336,91		19,00	78,78	3,50	1,69	13,5	10,5	12,0	0,0131	9096,4	189,5	20,0	20,0	2,5
				0			0%	19,00	118,17	3,50	2,34	0,0	0,0	0,2	0,0000	0,0	0,0	0,0		
TBA 1000 S	Female 79193	24	4	6	304	343,83		19,00	114,75	3,50	2,29	13,7	11,5	12,6	0,0133	9245,0	385,2	20,4	49,3	6,2
	Male 79194	24		6			0%	19,00	172,13	3,50	3,24	19,5	17,2	18,4	0,0188	13109,8	546,2	28,9		
TBA 125 S	Female 2883824	88	8	11	161	330,24		19,00	58,37	3,50	1,35	14,8	10,7	12,7	0,0143	9986,8	113,5	22,0	51,9	6,5
	Male 2883825	88		11			0%	19,00	87,56	3,50	1,83	20,2	16,1	18,1	0,0195	13590,9	154,4	29,9		
TT/3 500 MIDI	Female 2865283	54	6	9	213	382,03		19,00	89,33	3,50	1,86	16,8	13,4	15,1	0,0162	11299,5	209,2	24,9	59,7	7,5
	Male 2865284	54		9			0%	19,00	134,00	3,50	2,61	23,5	20,1	21,8	0,0227	15812,5	292,8	34,8		
TT/3 330 MIDI	Female 2865277	56	8	7	213	382,03		19,00	89,33	3,50	1,86	13,0	10,4	11,8	0,0126	8788,5	156,9	19,4	46,5	5,8
	Male 2865278	56		7			0%	19,00	134,00	3,50	2,61	18,3	15,6	17,0	0,0177	12298,6	219,6	27,1		
TBA 1000 S	Female 79193	12	4	3	304	343,83		19,00	114,75	3,50	2,29	6,9	5,7	6,4	0,0066	4622,5	385,2	10,2	29,4	3,7
	Male 79194	16		4			0%	19,00	172,13	3,50	3,24	13,0	11,5	12,3	0,0125	8739,9	546,2	19,3		
TBA 250 S	Female 2883940	48	6	8	187	352,72		19,00	72,41	3,50	1,58	12,7	9,7	11,2	0,0122	8524,2	177,6	18,8	44,7	5,6
	Male 2883941	48		8			0%	19,00	108,62	3,50	2,19	17,5	14,5	16,0	0,0169	11775,9	245,3	25,9		
TPA 500 SQ(cansled)	Female 3189771 Male 3189772 / 2591187																			
TBA 200 S	Female 2865115	36	6	6	173	330,44		19,00	62,76	3,50	1,42	8,5	6,3	7,4	0,0082	5743,0	159,5	12,7	32,8	4,1
	Male 2865116	42		7			0%	19,00	94,14	3,50	1,94	13,6	11,0	12,3	0,0132	9166,1	218,2	20,2		
TT3 1000 B	Female 2935152	28	4	7	264	312		19,00	90,43	3,50	1,88	13,2	10,5	11,9	0,0127	8874,4	316,9	19,6	46,9	5,9
	Male 2935153	28		7			0%	19,00	135,64	3,50	2,64	18,4	15,8	17,2	0,0178	12427,5	443,8	27,4		
TBA 1000 MID	Female 3120165	24	4	6	315	324,48		19,00	112,21	3,50	2,25	13,5	11,2	12,4	0,0130	9074,0	378,1	20,0	48,3	6,0
	Male 3120515	24		6			0%	19,00	168,32	3,50	3,18	19,1	16,8	18,0	0,0184	12853,2	535,5	28,3		
TBA 1000 MID	Female 3120165-0302	8	4	2	315	324,48		19,00	112,21	3,50	2,25	4,5	3,7	4,2	0,0043	3024,7	378,1	6,7	16,1	2,0
	Male 3120515-0302	8		2			0%	19,00	168,32	3,50	3,18	6,4	5,6	6,1	0,0061	4284,4	535,5	9,4		
TBA 1000 MID	Female 3120166	24	4	6	315	324,48		19,00	112,21	3,50	2,25	13,5	11,2	12,4	0,0130	9074,0	378,1	20,0	48,3	6,0
	Male 3120164	24		6			0%	19,00	168,32	3,50	3,18	19,1	16,8	18,0	0,0184	12853,2	535,5	28,3		
TBA 1000 MID	Female 3120166-0302	8	4	2	315	324,48		19,00	112,21	3,50	2,25	4,5	3,7	4,2	0,0043	3024,7	378,1	6,7	16,1	2,0
	Male 3120164-0302	8		2			0%	19,00	168,32	3,50	3,18	6,4	5,6	6,1	0,0061	4284,4	535,5	9,4		
TBA 500 B(Cansled)	Female 79601 Male 79963																			
TPA 250 SQ	Female 2987796	114	6	19	173	352,99		19,00	67,04	3,50	1,49	28,4	21,2	24,6	0,0274	19099,6	167,5	42,1	109,0	13,6
	Male 2987797/2987798	132		22			0%	19,00	100,56	3,50	2,05	45,1	36,9	40,7	0,0436	30394,4	230,3	67,0		
TBA 200 S	Female 2865115	36	6	6	173	330,44		19,00	62,76	3,50	1,42	8,5	6,3	7,4	0,0082	5743,0	159,5	12,7	32,4	4,0
	Male 2865116	41		7			0%	19,00	94,14	3,50	1,94	13,3	10,7	12,0	0,0128	8947,8	218,2	19,7		
												1034,39	841,70	939,67	1,00	696750,00	######	1535,10	1535,10	

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							inbound							Hardening						grinding						outbound			
Orders 2011	***utlev av rör***	***Leverans på Ferrmek***	***Verklig.Lev(Halvfab.)***	***Arbetsdagar på Ferrmek***	Theoretical	diff	wait in inbound	Inventory time, inbound	avverage inventory	CoC inventory	CoC process	CoC Operation	restricted total capital cost	Inventory time	avverage inventory	CoC inventory	CoC process	CoC Operation	restricted total capital cost	Inventory time	avverage inventory	CoC inventory	CoC process	CoC Operation	restricted total capital cost	Inventory time	avverage inventory	CoC inventory	restricted total capital cost
TT3 1000 CC	25-nov	27-nov	16-dec 16-dec	14	21	-7	0	6,7	8,0	138,2	138,2	22,7	**299,1**	9,3	8,0	192,4	144,3	30,4	**666,3**	6,9	8,0	142,3	142,3	82,1	**1032,8**	1,0	8,0	20,6	**1053,5**
TBA 200 B	08-dec	10-dec	10-jan 10-jan	22	17	5	0	5,6	8,0	93,2	93,2	15,9	**202,4**	9,3	8,0	154,9	116,2	53,2	**526,8**	3,3	8,0	55,0	55,0	18,9	**655,6**	1,0	8,0	16,6	**672,2**
TBA 200 S	12-jan	14-jan	27-jan 27-jan	10	18	-8	0	6,2	10,0	112,1	112,1	19,7	**243,8**	11,7	10,0	209,5	125,7	71,3	**650,2**	3,6	10,0	65,4	65,4	22,9	**803,9**	1,0	10,0	18,0	**821,9**
TBA 200 B	02-jan 02-feb	04-jan	22-feb 22-feb	36	17	19	10	15,6	8,0	259,2	259,2	44,2	**562,7**	9,3	8,0	154,9	116,2	53,2	**887,1**	3,3	8,0	55,0	55,0	18,9	**1016,0**	1,0	8,0	16,6	**1032,6**
TBA 500 B	31-jan	02-feb	10-feb	7	6	1	0	0,4	0,5	0,7	0,7	0,1	**1,4**	0,6	0,5	0,9	11,2	0,2	**13,7**	0,3	0,5	0,5	0,5	0,2	**15,0**	1,0	0,5	1,6	**16,6**
TT 200 Mini	27-jan	29-jan	22-feb 22-feb	17	17	0	8	13,8	9,0	231,6	231,6	40,3	**503,5**	10,5	9,0	175,9	117,3	77,0	**873,7**	3,6	9,0	60,0	60,0	22,1	**1015,8**	1,0	9,0	16,8	**1032,6**
TPA 200 SQ	02-feb	04-feb	03-mar 03-mar	20	26	-6	0	13,0	19,5	491,4	491,4	84,7	**1067,5**	22,8	19,5	862,5	265,4	316,3	**2511,7**	7,6	19,5	288,2	288,2	99,6	**3187,6**	1,0	19,5	37,9	**3225,5**
TBA 200 S	16-feb	18-feb	14-mar 14-mar	17	18	-1	0	6,2	10,0	112,1	112,1	19,7	**243,8**	11,7	10,0	209,5	125,7	71,3	**650,2**	3,6	10,0	65,4	65,4	22,9	**803,9**	1,0	10,0	18,0	**821,9**
TBA 1000 SQ	25-feb	27-feb	05-maj 2011-03-18 / 2011-05-05	49	21	28	0	6,2	6,0	124,2	124,2	19,4	**267,8**	7,0	6,0	140,0	140,0	17,1	**564,9**	6,4	6,0	128,2	128,2	70,9	**892,3**	1,0	6,0	20,0	**912,3**
TBA 1000 B	18-feb	20-feb	18-apr 18-apr	41	20	21	7	12,9	6,0	243,2	243,2	38,7	**525,0**	7,0	6,0	131,6	131,6	17,1	**805,4**	6,1	6,0	113,8	113,8	63,2	**1096,3**	1,0	6,0	18,8	**1115,1**
TBA 250 B	16-feb	18-feb	13-apr 13-apr	39	17	22	2	7,6	8,0	126,4	126,4	21,6	**274,3**	9,3	8,0	154,9	116,2	45,6	**591,0**	3,2	8,0	53,2	53,2	17,7	**715,2**	1,0	8,0	16,6	**731,8**
TBA 250 S																													
TBA 1000 S																													
TBA 125 S	04-mar	06-mar	05-apr 05-apr	22	18	4	0	6,5	11,0	119,3	119,3	21,3	**259,8**	12,8	11,0	235,7	128,6	115,0	**739,1**	4,1	11,0	75,0	75,0	28,7	**917,8**	1,0	11,0	18,4	**936,2**
TBA 1000 B	21-mar	23-mar	26-apr	25	10	15	0	2,5	3,0	23,1	23,1	3,0	**49,2**	3,5	3,0	32,9	65,8	4,3	**152,2**	3,0	3,0	28,5	28,5	15,8	**224,9**	1,0	3,0	9,4	**234,3**
TBA 1000 S	18-mar	20-mar	16-maj	41	10	31	3	5,5	3,0	54,8	54,8	7,1	**116,6**	3,5	3,0	34,6	69,1	4,3	**224,6**	3,2	3,0	31,2	31,2	17,2	**304,3**	1,0	3,0	9,9	**314,1**

Appendix C-2

TPA 1000 SQ	29-mar	31-mar	16-maj	33	15	18	0	5,3	6,5	110,8	110,8	14,4	**236,0**	7,6	6,5	157,2	145,1	20,1	**558,4**	6,7	6,5	138,2	138,2	76,6	**911,3**	1,0	6,5	20,7	**932,1**
TGA 1000 SQ Octagonal	08-apr	10-apr	11-maj 11-maj	23	15	8	0	2,8	3,3	28,7	28,7	3,9	**61,3**	3,8	3,3	39,4	72,7	5,0	**178,4**	3,4	3,3	35,6	35,6	20,2	**269,8**	1,0	3,3	10,4	**280,1**
TGA 1000 SQ Octagonal	08-apr	10-apr	11-maj 11-maj	23	15	8	0	2,8	3,3	28,7	28,7	3,9	**61,3**	3,8	3,3	39,4	72,7	5,0	**178,4**	3,4	3,3	35,6	35,6	20,2	**269,8**	1,0	3,3	10,4	**280,1**
TGA 1000 SQ Octagonal	08-apr	10-apr	11-maj 11-maj	23	15	8	0	2,8	3,3	28,7	28,7	3,9	**61,3**	3,8	3,3	39,4	72,7	5,0	**178,4**	3,4	3,3	35,6	35,6	20,2	**269,8**	1,0	3,3	10,4	**280,1**
TGA 1000 SQ Octagonal	08-apr	10-apr	11-maj 11-maj	23	15	8	0	2,8	3,3	28,7	28,7	3,9	**61,3**	3,8	3,3	39,4	72,7	5,0	**178,4**	3,4	3,3	35,6	35,6	20,2	**269,8**	1,0	3,3	10,4	**280,1**
TBA 80 S	20-maj	22-maj	10-jun 10-jun	15	18	-3	0	5,9	11,0	96,3	96,3	17,7	**210,3**	12,8	11,0	208,5	113,7	129,4	**661,9**	4,0	11,0	64,2	64,2	26,9	**817,3**	1,0	11,0	16,2	**833,5**
TBA 300 S	26-apr	28-apr	29-jun	45	8	37	24	26,5	4,0	239,2	239,2	33,5	**512,0**	4,7	4,0	42,1	63,2	11,4	**628,7**	1,7	4,0	15,4	15,4	5,0	**664,6**	1,0	4,0	9,0	**673,6**
TBA 1000 S	10-maj	12-maj	12-jul 12-jul	44	20	24	0	6,2	6,0	121,6	121,6	19,1	**262,2**	7,0	6,0	138,2	138,2	17,1	**555,8**	6,3	6,0	124,9	124,9	69,0	**874,6**	1,0	6,0	19,7	**894,3**
TBA 125 S	09-jun	11-jun	04-jul 04-jul	16	18	-2	0	6,5	11,0	119,3	119,3	21,3	**259,8**	12,8	11,0	235,7	128,6	115,0	**739,1**	4,1	11,0	75,0	75,0	28,7	**917,8**	1,0	11,0	18,4	**936,2**
TT/3 500 MIDI	25-aug	27-aug	23-sep 23-sep	20	19	1	0	7,5	9,0	173,2	173,2	28,1	**374,6**	10,5	9,0	243,6	162,4	57,8	**838,3**	4,2	9,0	97,6	97,6	30,5	**1064,1**	1,0	9,0	23,2	**1087,3**
TT/3 330 MIDI	09-sep	11-sep	30-sep	15	17	-2	0	5,8	7,0	104,8	104,8	17,0	**226,6**	8,2	7,0	147,4	126,3	46,6	**546,9**	3,5	7,0	62,7	62,7	20,8	**693,0**	1,0	7,0	18,0	**711,1**
TBA 1000 S	22-feb	24-feb	12-jul 12-jul	99	16	83	199	202,7	3,5	2334,5	2334,5	376,2	**5045,2**	4,1	3,5	47,0	80,6	5,8	**5178,7**	3,7	3,5	43,1	43,1	24,1	**5288,9**	1,0	3,5	11,5	**5300,5**
TBA 250 S	02-mar	04-mar	14-mar 14-mar	7	17	-10	0	5,6	8,0	93,0	93,0	15,8	**201,8**	9,3	8,0	155,3	116,5	45,6	**519,2**	3,2	8,0	53,6	53,6	17,9	**644,2**	1,0	8,0	16,6	**660,9**
TPA 500 SQ(cansled)																													
TBA 200 S	21-jan	23-jan	14-feb	16	15	1	0	4,1	6,5	47,9	47,9	8,5	**104,3**	7,6	6,5	88,5	81,7	30,1	**304,6**	2,4	6,5	28,1	28,1	10,0	**370,8**	1,0	6,5	11,7	**382,5**
TT3 1000 B	26-okt	28-okt	28-nov	22	20	2	0	5,9	7,0	105,8	105,8	17,4	**229,0**	8,2	7,0	147,3	126,3	23,3	**525,9**	6,1	7,0	109,4	109,4	63,4	**808,1**	1,0	7,0	18,0	**826,1**
TBA 1000 MID	12-okt	14-okt	14-nov	22	20	2	14	20,0	6,0	385,5	385,5	61,0	**832,0**	7,0	6,0	134,7	134,7	17,1	**1118,5**	6,2	6,0	118,9	118,9	65,8	**1422,1**	1,0	6,0	19,2	**1441,4**
TBA 1000 MID	12-okt	14-okt	24-nov	30	13	17	0	2,0	2,0	12,9	12,9	2,0	**27,9**	2,3	2,0	15,0	44,9	1,9	**89,6**	2,1	2,0	13,7	13,7	7,9	**125,0**	1,0	2,0	6,4	**131,4**
TBA 1000 MID	12-okt	14-okt	01-dec	35	20	15	0	6,0	6,0	116,2	116,2	18,4	**250,7**	7,0	6,0	134,7	134,7	17,1	**537,2**	6,2	6,0	118,9	118,9	65,8	**840,8**	1,0	6,0	19,2	**860,1**
TBA 1000 MID	12-okt	14-okt	14-dec	44	13	31	0	2,0	2,0	12,9	12,9	2,0	**27,9**	2,3	2,0	15,0	44,9	1,9	**89,6**	2,1	2,0	13,7	13,7	7,9	**125,0**	1,0	2,0	6,4	**131,4**
TBA 500 B(Cansled)																													
TPA 250 SQ	18-nov	20-nov	30-dec	30	27	3	0	13,6	20,5	538,1	538,1	93,7	**1169,9**	23,9	20,5	944,2	276,3	299,6	**2690,1**	7,7	20,5	303,4	303,4	101,8	**3398,6**	1,0	20,5	39,5	**3438,1**
TBA 200 S	05-okt	07-okt	07-nov	22	17	5	44	48,0	6,4	553,5	553,5	98,0	**1205,0**	7,5	6,4	86,2	80,6	29,4	**1401,3**	4,1	6,4	47,7	47,7	29,5	**1526,1**	1,0	6,4	11,5	**1537,6**
			medel	28	17	11	311	494	7	**7410**	**7410**	**1218**	**16038**	286	7	**5788**	**3963**	**1766**	**27554**	146	7	**2733**	**2733**	**1234**	**34253**	35	7	**566**	**34819**

Project in Production and Material Engineering

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LUND UNIVERSITY
Lund Institute of Technology

A Study in Hot Forming
Of
High Strength Steel

Andreas Eriksson

2013

DEPARTMENT OF MECHANICAL ENGINEERING
LUND INSTITUTE OF TECHNOLOGY

Summary

This report summarizes the methods of performance and results of a project within hot forming of high strengthen steels. The background to the project is the question whether an existing production process of creasing tools made by high strengthen steel could be processed different by the use of hot forming, rather than the mechanical machining process used today. Different materials are hot formed hardened and measured to determine if the method shows promising or not. The initiator to the project is Tetra Pak Creasing in Lund who is looking at different new ways to enhance their current production processes of creasing tools. The main scope is to drastically reduce processing time, waste and cost while maintaining or even improving the quality of the tools. All tests have been performed at the department of mechanical engineering at Lund Institute of Engineering. The manufacturing of forming tools used for the test is supplied by Tetra Pak Creasing and all materials used to form are supplied by Uddeholms.

Contents

1 Introduction

1.1 Background

Tetra Pak is the world leading manufacturer of liquids food packaging's, and offers there costumer complete processes solutions from tank to filled packages ready to be put on shelf's and sold in store. A critical and very important part of the Tetra Pak business is the manufacturing of Packaging material that is carried out in more than 40 converting factories around the world. [11]

1.2 The manufacturing Creasing Plates

The packages are produced in special, by Tetra Pak developed and manufactured filling machines to obtain the correct shape and look. For the machines to function properly, creases are imprinted into the packaging material making it to fold easier, at wanted place, forming the desired form of the package.

Figur 1 Picture of creased Tetra Pak paperboard [13]

These operations are carried out in roller mill stations integrated within the printing presses where the pattern imprinted to the packaging material are made by special plates mounted to the rolls. The plates are called "Creasing plates" and are the component that underlies this study. Tetra Pak Creasing delivers plates both as spare parts and as components for new creasing tools. About 50 percent of all produced plates are used as spare parts.[9][10]

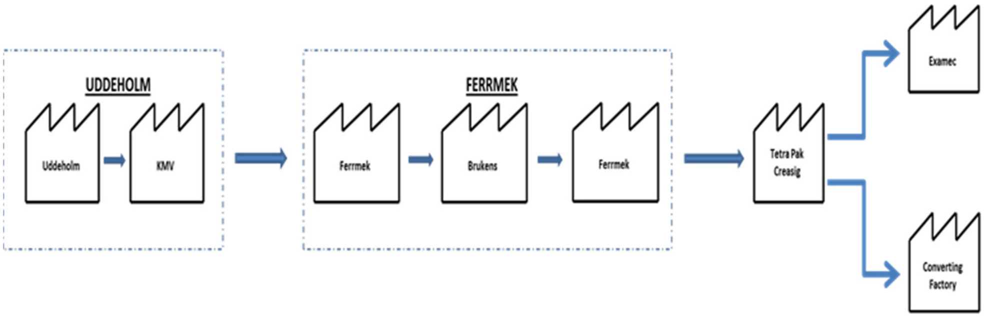


Figure 2 The Supply Chain

1.2.1 Current Method of Manufacture

The manufacturing process of the creasing plates goes through three companies. Uddeholms is the first supplier in the chain and deliver the material in form of two meter rods. The rods are delivered to KMV who drills the rods into tubes. The third company is Ferrmek who processes the tubes into plates and uses Brukens to provide the hardening process. The last step in the chain is processed in house at Tetra Pak, before the plates are finish and sent to customer.[9][10]

KMV

The manufacturing of tubes is done by drilling 2 meter long rods into thin shelved tubes with the diameter required to make the creasing plate fit on the milling roll. Tetra Pak offers a wide range of different packages and the variety of creasing patterns are therefore large and requires many different tube diameters. The tubes are cut into smaller tubes long enough to fit one turn of plates and then lathed both inside and outside. Finally the tubes are stress relieved to prevent large deformations during hardening later down the process.[9][10]

Ferrmek

The manufacturing of semi-finished creasing plates is done by milling the approximated crease pattern and various hole for mounting on the roll before finally cutting the tube into single plates. The plates are then hardened and finally grained to proper dimensions.

Tetra Pak

The final processing of the crease pattern is done in house at Tetra Pak in Lund. To obtain the final crease pattern, small edges and ducts are formed by electro discharge machining (EDM). Finally the plates are sandblasted to blunt sharp edges.

1.2.2 Challenging Method of Manufacture

Tetra Pak is constantly working on improving their production processes and is always looking into newer ways to manufacture the creasing plates, were waste, time and costs can be reduced. The challenging process this report discusses is based on the theory that time and money could be saved if a plate could be hot formed from a straight plate instead of current method where machining operations is used in all steps of the process.

The idea is to heat up a plate to desired temperature and form it with a high pressure tool. This takes only a fraction of the time it takes to drill a tube from a solid rod and drastic reduces the waste. All other processes are then the same as before, but with the differences that it is single plates that are handled and not tubes.

Another idea is to harden the plates during hot formed and then only processing the plates by EDM. This requires a tool that can cool the plate fast enough to make the material to form martensite. It also requires an annealing process directly after the forming process preventing the material to self crack.

1.3 Purpose and Delimitations

1.3.1 Purpose

The purpose of this study has been to evaluate the possibility of using a straight plate instead of a tube, and by hot forming making the radius needed to manufacture a creasing plate. It has earlier been identified that the most time consuming processing steps have been the grinding process due to deformations in the material during hardening process. Therefore the objective of this study has been to evaluate the form stability of the plates before and after hardening. Other observations has also been done, such as surface finish, edge and hole deformations and visual inspection to find possible crack formations caused by the forming method.

If the manufacture method by using hot forming finds trust worthy, it has the ability to make a major impact on both costs and lead time by a dramatic reduction of processing waste, labor hours and processing time.

1.3.2 Delimitations

This study is limited to the forming of straight plates, all with the same size. The amount of plates is only three per batch and only three types of material are tested. Which materials to be tested has in advanced been determined by Tetra Pak. This report will cover the measuring of hot formed plates to determine the degree of deviation and visual inspection of the surfaces. Further analyzes of the material have been made by Tetra Pak but is not covered in this report.

2 Theoretical Framework.

2.1 Hot Forming treatment of Steel

To be able to hot form a high strength steel many variables has to be considered. The temperature determines the strength and therefore the load that's needed to form the plate. The load determines the design of the tool and the heat transfer from the plate to the tool, the cooling needed to prevent the tool to collapse. The temperature of the plate also determine whether the material will start to transform into austenite which when cooled will form martensite and a hardening of the steel has taken place. It's satisfying to heat the material as much as possible without risking any austenite transformation to get the material as soft and formable as possible. In other hand, if a hardening of the material is desirable, the material should be heated to full austenite transformation is reached and then cooled quickly. If done, the next treatment of the steel has to be annealing, where the material is heated two more times to get rid of the rest martensite left in the material. This report will cover test with temperatures both causing the material to transform into austenite and not. [1] [2]

2.1.1 Forming Without Hardening

When forming without hardening the material should not be heated to higher temperature for which the transformation to austenite starts. This temperature is given from the the specifications of the material. The material can then be cooled rapidly without risking any martensite formations and therefore no annealing process has to follow. However, the forming process has introduced internal tensions and therefore the material should be stress relieved by heat treatment up to about 75 °C below the transformation temperature of the material. The temperature used in this report for heat treatments are found in the brochure delivered by Uddeholms for every specific material. The main purpose of stress relief treatment is to prevent the material from changing form during hardening. [2]

2.1.2 Forming With Hardening

A hot forming process where the material is formed and hardened in the same processing step is interesting since it will save time. Important if used, is to immediately follow the heat forming with an annealing process before the material is cooled below 100-200 ˚C. Since the material is heated up to full austenite formation and then rapidly cooled, a large percent of martensite is left within the material. Martensite has larger volume than the rest of the material and very high stresses are therefore introduced within the material. If letting the material to cool bellow 100-200 ˚C without any annealing, the differences in volume within the material could create internal stresses large enough making the material to self-crack. [2]

2.2 Statistical Process control

A high quality manufacturing line is very dependent on the repeatability of the process. Narrow tolerances on the finished plates put high demands on the process line not to incur large costs caused by disposal of plates and redoing of plates not within the demanded tolerances. To insure a high repeatability it's therefore important to strive for and maintain a static process where the deviations are strictly random. All other factors due to manual handling, temperatures, wear and others that have an effect on the process must be identified and eliminated. To do this, Multivariate Factor Analysis could be used. This method is based on finding all factors affecting the outcome and to determine their impact on the process. The different factors are changed during tests and then analyzed using a normal distribution plot. The factors that deviates the most from the normal distribution are the factors with largest impact on the outcome. [3][7]

2.2.1 Deviations

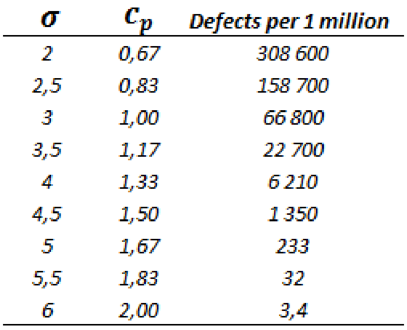
The Six-Sigma method states that the standard deviation of every process step should be no larger than ±1/6 of the tolerance limits. This will ensure no more than 3.4 errors per one million produced plates. [3] To be able to do so without continues controlling and measuring every part, the effect of manual processing steps must be reduced or controlled by the use of fixtures and, or, other tools to eliminate the chance of deviations. Six-Sigma is however considered quite strict and hard to reach, and four-sigma is therefore a more common used quality level. Four-sigma ensures not more than 6 210 defect plates of 1 million produced. When determine the deviations of a plate, both deviations in diameter and uniformity of the surface must be considered. Following equations could be used for this. [3]

$$\sigma_{uniformity} = \sqrt{\frac{1}{k}\sum_{j=1}^{k}\sigma_{deviation,j}^{2}} \tag{1}$$

$$\sigma_{diameter} = \sqrt{\frac{1}{k-1}\sum_{j=1}^{k}\left(\bar{\emptyset}_j - \bar{\bar{\emptyset}}\right)^2} \tag{2}$$

$$\sigma_{tot}^{*} = \sqrt{\sigma_{uniformity}^{2} + \sigma_{diameter}^{2}} \tag{3}$$

$$\mu^{*} = \frac{1}{k}\sum_{j=1}^{k}\bar{\emptyset}_j \tag{4}$$



σ	c_p	Defects per 1 million
2	0,67	308 600
2,5	0,83	158 700
3	1,00	66 800
3,5	1,17	22 700
4	1,33	6 210
4,5	1,50	1 350
5	1,67	233
5,5	1,83	32
6	2,00	3,4

Figure 3 Defects per 1 million produced plates according to Six-sigma[3]

3 Method

3.1 Material Propertis

The materials to be tested are two high strength steels, Caldie and Vanadis 4 Extra and are both delivered by Uddeholms. The current steel used today is Sverker 21, and is a steel developed for more than 60 years ago. Caldie and Vanadis 4 Extra are more modern steels, recommended by Uddeholms to replace the Sverker 21 steel.

Caldie[1]

Delivery condition:
Annealed to ≈ 18 HRC
Typical Analysis: [C0,7|Si0,2|Mn0,5|Cr5,0|Mo2,3|V0,5]

[i]**Hardened to ≈ 61 HRC:**
Density: 7 820 kg/m^3
Young's-Module: 213 GPa
Specific Heat: 460 J/kg˚C
[ii]*Stress Relief Temperature*: 650˚C
Annealing Temperature: 820˚C
Start of Austenitizing Temperature: 805˚C
Full Austenitizing teperature: 1000˚C

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[i] Heated to 1025˚C and Annealed two times at 525˚C
[ii] Heated to 650˚C and holed for 2hours. Cool slowly to 500˚C and then free in air

Vanadis 4 Extra[1]

Delivery condition:
Annealed to ≈ 21 HRC
Typical Analysis: [C1,4|Si0,4|Mn0,4|Cr4,7|Mo3,5|V3,7]

[i]**Hardened to ≈ 60 HRC:**
Density: 7 700 kg/m^3
Young's-Module: 206 GPa
Specific Heat: 460 J/kg ˚C
[ii]*Stress Relief Temperature:* 650 ˚C
Annealing Temperature: 900˚C
Start of Austenitizing Temperature: 860 ˚C
Full Austenitizing teperature: 1025 ˚C

3.2 Heat Treatment

For heat treatment of the materials a muffle furnace is used. All handling are manual and there is no use of gases or other protective methods during the heating. For heat treatment before forming a smaller muffle furnace is used to simplify the manual handling. During stress relief, annealing and hardening a larger programmable muffle furnace is used. The forming is made in a special designed tool mounted on a hydraulic press with a capacity of creating loads up to 600 tons.

The material is heated to 600 ˚C, 820 ˚C(Caldie), 860˚C (Vanadis4E) and 1050 ˚C. The material will then be cooled in the tool when formed by a load of 320 tons. To be able to cool the material fast and preventing the temperature of the tool rising above critical point regarding material strength. The tool are water-cooled through 8 channels with a volume flow of 1dm3 per second. [1]

The temperatures not exceeding 820 ˚C (Caldie) and 860 ˚C (Vanadis4E) will not start any austenite transformation in the materials and will therefore not form any Martensite. The material will then be stressed relieved at 650 ˚C and hardened at 1050 ˚C. [1]

---

[i] Heated to 1025 ˚C and Annealed two times at 525 ˚C
[ii] Heated to 650 ˚C and holed for 2hours. Cool slowly to 500 ˚C and then free in air

Temperatures reaching above austenitizing temperature, 1050 ˚C, will form Martensite and will need to be annealed two times at [i]540 ˚C and 525 ˚C to prevent crack formations.[1]

3.3 Forming Method

A tool in two halves is used to form the straight plate into the wanted radius. The tool is designed with stop lugs to prevent more force than needed to be applied on the plate causing it to squeeze and loose its preferred thickness. This allows the press force to be set high enough, ensuring the tool halves to always become completely together during the press cycle.

3.3.1 Tool Design

The tool is designed using Pro-Engineer where the idea is that the two halves is made out of one solid block by wire-EDM. The maximum yield stress and deformations with applied force are calculated using [ii]Mechanica in Pro-Engineer. To determine maximum allowed yield stress of the tool during forming, the maximum yield stress of the material when 200˚C are used (≈90% of yield stress at 20˚C).[4]

Material: **structural steel 14 13 12-00**
Maximum Yield stress$_{@20\,℃}$: 240MPa
Maximum Yield stress$_{@200\,℃}$: 216MPa
Young's-Module$_{@20\,℃}$: 208 GPa
Young's-Module$_{@200\,℃}$: 208 GPa
[4][5]

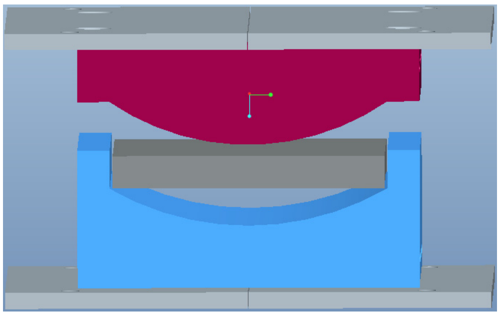


Figure 4 Model of forming tool in Pro-Engineer in unformed state

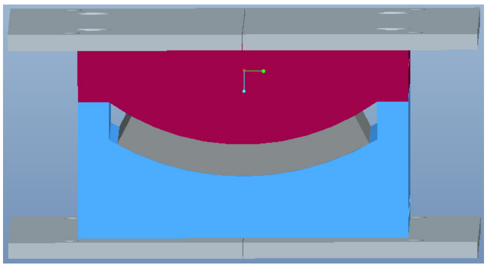


Figure 5 Model of forming tool in Pro-Engineer in formed state

[i] The temperatures 540˚C and 525˚C is to attain a hardness of 63 HRC and is found in the brochure from Uddeholm[1]

[ii] An application within Pro-Engineer that uses the Finite Element Method to calculate maximum yield stress and deformation in the model

With the help of FEM the tool where anayzed and the lower tool reached a maximum yield stress level at 221,6MPa at 500 tons load which is just below the maximum allowed yield stress for this material (240MPa@20 ˚C) [5]. The tool will also be heated by the warm plate during the forming process and the maximum allowed yield stress at 200 ˚C is 216 MPa. 200 tons at 600 ˚C where the smallest load for which the test plates where completely formed, and the tool halfs was brought completely together. However, the lugs on the lower tool could only hold a load of maximum 192 tons if pressed together empty without a plate between. The upper tool would hold for 1000 ton at 200 ˚C. To ensure that the load would be large enough during all tests, it was set to 320 tons. This since it would be more then enough to ensure full fomation of the plates and still far from creating stresses in material close to the limit of 240 MPa. And this even if the material it in some places should be heated as high as to 200 ˚C.

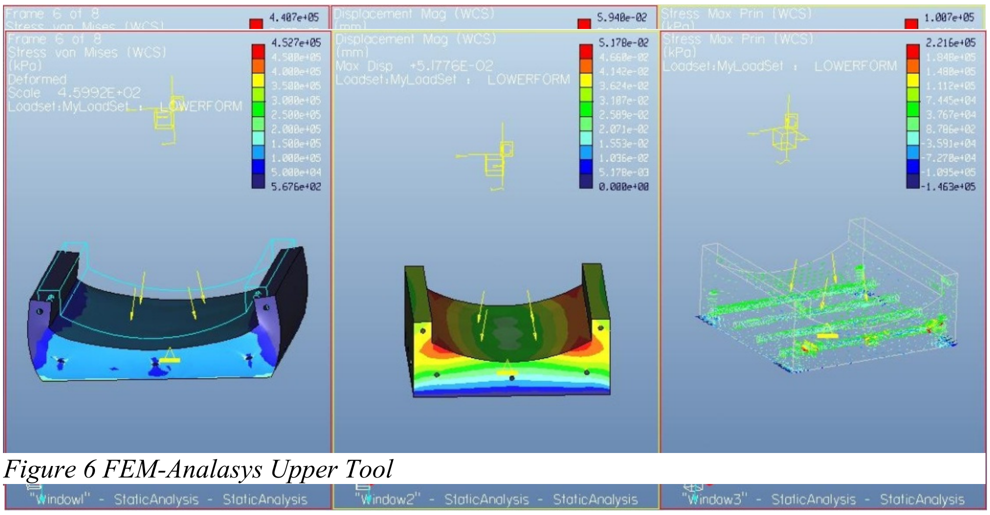


Figure 6 FEM-Analasys Upper Tool

3.4 Measurement

Measuring of the formed plates is made at Tetra Pak Creasing where a coordinate measuring machine (CMM) is used. The same machine Tetra Pak Creasing is using to control the quality of the finished creasing plates. The plates are measured one or three times depending on the test. Batches heated to 600 ˚C and ~900 ˚C is measured three times. After forming, stress relieve and hardening. Plates heated to about 1050 ˚C are hardened in the forming tool and are therefore directly annealed before cooling

Figure 7 FEM-Analysis Lower Tool

below about 150 ˚C. These plates are measured only one time, after annealing.

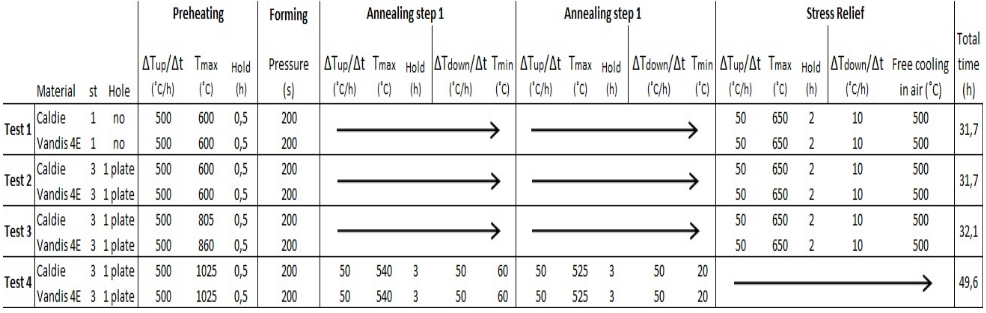
3.5 Form Stability

The main objectives with these tests are to determine the form stability in the material when using hot forming as a manufacture method. The plates heated to maximum 860 ˚C are measured before stress relieving process to evaluate the dimension spread due to divergences after hot forming. The plates are then measured again after stress relive treatment and again after hardening. The plates are expected to have the largest dimensional changes after stress relive treatment due to internal tensions resulted by the deformation hardening that occur when formed. The plates heated to 1050 ˚C are measured only one time after the annealing process. But are then not heat treated again, and therefore not expected to have any significant dimension changes after this processing step. [1][6]

4 Validation

4.1 Test Plan

Uddeholms provided 10 plates of each material with the recommendations to try to form the plates between 600 ˚C and up to the temperature when formations to austenite start, 820 ˚C for Caldie and 860 ˚C for Vanadis4E. Since the possibility to be able to form and harden the plates at the same operation is highly interesting, this was as well implemented in the test plan. One plate of each material where expected to be wasted during calibrating pressure load and cooling capacity. Remaining 9 plates per material would then be enough for three tests per temperature.



				Preheating			Forming	Annealing step 1					Annealing step 1					Stress Relief					Total
	Material	st	Hole	ΔTup/Δt (˚C/h)	Tmax (˚C)	Hold (h)	Pressure (s)	ΔTup/Δt (˚C/h)	Tmax (˚C)	Hold (h)	ΔTdown/Δt (˚C/h)	Tmin (˚C)	ΔTup/Δt (˚C/h)	Tmax (˚C)	Hold (h)	ΔTdown/Δt (˚C/h)	Tmin (˚C)	ΔTup/Δt (˚C/h)	Tmax (˚C)	Hold (h)	ΔTdown/Δt (˚C/h)	Free cooling in air (˚C)	time (h)
Test 1	Caldie	1	no	500	600	0,5	200	→					→					50	650	2	10	500	31,7
	Vandis 4E	1	no	500	600	0,5	200											50	650	2	10	500	
Test 2	Caldie	3	1 plate	500	600	0,5	200	→					→					50	650	2	10	500	31,7
	Vandis 4E	3	1 plate	500	600	0,5	200											50	650	2	10	500	
Test 3	Caldie	3	1 plate	500	805	0,5	200	→					→					50	650	2	10	500	32,1
	Vandis 4E	3	1 plate	500	860	0,5	200											50	650	2	10	500	
Test 4	Caldie	3	1 plate	500	1025	0,5	200	50	540	3	50	60	50	525	3	50	20	→					49,6
	Vandis 4E	3	1 plate	500	1025	0,5	200	50	540	3	50	60	50	525	3	50	20						

Figure 8 Test plan.

4.2 Execution

Two muffle furnaces (one small and one large) where place closed to the press to ease the inserting and removal of the hot plate in the tool. The small furnace where used to heat the plates since this furnace is easier to handle with higher temperatures. The larger furnace where used for secondary heat treatments as stress relieves and annealing processes. The larger furnace also had the capability to be programmed which where a requirement since this processes takes many hours.

The tools where mounted in a press with a estimated capacity of ≈600ton. Since the pressure load where shown only in MPa, the piston of the press where measured and the expected load in ton where calculated.

Piston perimeter [s]: 1290 mm

$$A = \pi r^2 \tag{5}$$

$$s = 2\pi r \tag{6}$$

$$(1) + (2) \rightarrow A_{piston} = \frac{s^2}{4\pi} = 0{,}132m^2 \tag{7}$$

$$F = PA \tag{8}$$

$$P_{scale} = 23{,}8\ Mpa \ \rightarrow F = 3139200N \ \approx 320ton$$

The pressure of the press where set to 23.8 MPa to obtain the correct pressing load.

To control and log the temperatures of plate and too, an IR-Camera where installed on the back side of the press, letting it to monitor both the tool and plate during the hole operation. Also an ordinary camera where used to capture the tests on film.

To control the water flow a valve where mounted on the output of the cooling water channels. After calibrating the pressure load and measuring the temperature of the tool when forming plates up to 860 ˚C the water flow where set to maximum flow which is 1dm3 per second. The tool never gets even close to rise over 200 ˚C during the tests.

4.2.1 Heated and Formed Without Martensite Formation

The first three tests where never heated to temperatures over the austenitizing temperature, and therefore never formed any martensite. The plates where then sand blasted and measured before heat treated again to 650 ˚C for tress relieve and then measured a second time to detect any dimensional changes during the heat treatment. Finally the plates where hardened and again sand blasted and measured. The expected major dimensional change was to happen during stress relief, since this is the first heat treatment after the forming operation. The plates are also expected to be some hardened by deformation since the temperature never reaches the level needed for annealing.

4.2.2 Hardening and Forming in one Execution

During the fourth and last test, the plates where heated to 1050 ˚C which is the temperature of full formation to austenite. The plates where then cooled to about 150 ˚C under 320 tons pressure before again placed in the furnace. To be able to anneal all six plates at the same time the furnace where set to 150 ˚C to protect the plates from self cracking due to large inner tensions caused by the volume different of retained austenite and martensite. When all six plates where formed the furnace where programmed to anneal the plates two times at the temperatures 525 ˚C and 540 ˚C. The plates where then sand blasted and measured.

The hardness of the plates where expected to be 63 HRC.

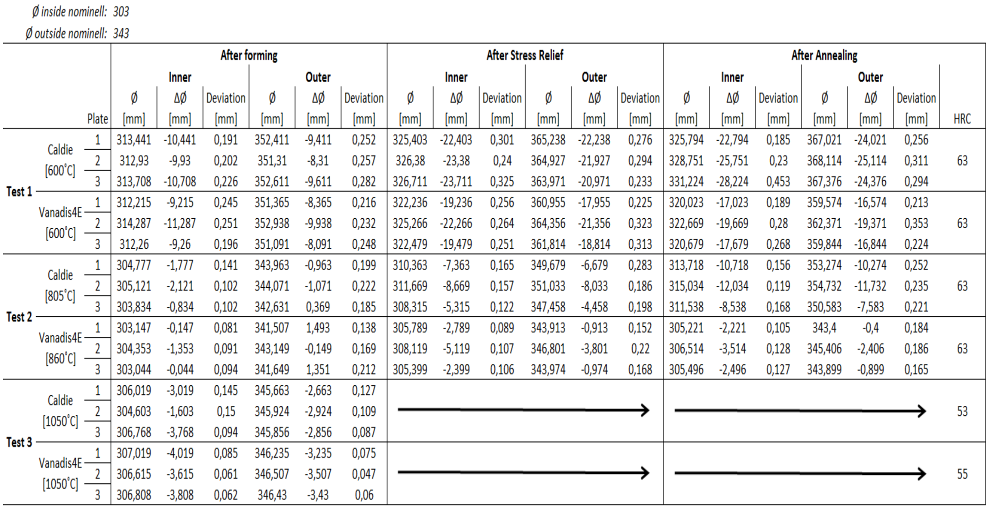
4.3 Measuring

The dimensions and hardness are measured at Tetra Pak with the same method always used to control the tolerances of the creasing plates. CMM measures more than 100 points on the plate and then calculates the mean radius and surface uniformity. The measuring report shows the maximum deviations and the different from the expected radius.

5 Results

5.1 Deviations

The plates are measured in three steps to capture the dimensional changes in the plates due to different heat treatments.



Ø inside nominell: *303*
Ø outside nominell: *343*

			After forming						After Stress Relief						After Annealing						
			Inner			Outer			Inner			Outer			Inner			Outer			
		Plate	Ø [mm]	ΔØ [mm]	Deviation [mm]	Ø [mm]	ΔØ [mm]	Deviation [mm]	Ø [mm]	ΔØ [mm]	Deviation [mm]	Ø [mm]	ΔØ [mm]	Deviation [mm]	Ø [mm]	ΔØ [mm]	Deviation [mm]	Ø [mm]	ΔØ [mm]	Deviation [mm]	HRC
Test 1	Caldie [600˚C]	1	313,441	-10,441	0,191	352,411	-9,411	0,252	325,403	-22,403	0,301	365,238	-22,238	0,276	325,794	-22,794	0,185	367,021	-24,021	0,256	63
		2	312,93	-9,93	0,202	351,31	-8,31	0,257	326,38	-23,38	0,24	364,927	-21,927	0,294	328,751	-25,751	0,23	368,114	-25,114	0,311	
		3	313,708	-10,708	0,226	352,611	-9,611	0,282	326,711	-23,711	0,325	363,971	-20,971	0,233	331,224	-28,224	0,453	367,376	-24,376	0,294	
	Vanadis4E [600˚C]	1	312,215	-9,215	0,245	351,365	-8,365	0,216	322,236	-19,236	0,256	360,955	-17,955	0,225	320,023	-17,023	0,189	359,574	-16,574	0,213	63
		2	314,287	-11,287	0,251	352,938	-9,938	0,232	325,266	-22,266	0,264	364,356	-21,356	0,323	322,669	-19,669	0,28	362,371	-19,371	0,353	
		3	312,26	-9,26	0,196	351,091	-8,091	0,248	322,479	-19,479	0,251	361,814	-18,814	0,313	320,679	-17,679	0,268	359,844	-16,844	0,224	
Test 2	Caldie [805˚C]	1	304,777	-1,777	0,141	343,963	-0,963	0,199	310,363	-7,363	0,165	349,679	-6,679	0,283	313,718	-10,718	0,156	353,274	-10,274	0,252	63
		2	305,121	-2,121	0,102	344,071	-1,071	0,222	311,669	-8,669	0,157	351,033	-8,033	0,186	315,034	-12,034	0,119	354,732	-11,732	0,235	
		3	303,834	-0,834	0,102	342,631	0,369	0,185	308,315	-5,315	0,122	347,458	-4,458	0,198	311,538	-8,538	0,168	350,583	-7,583	0,221	
	Vanadis4E [860˚C]	1	303,147	-0,147	0,081	341,507	1,493	0,138	305,789	-2,789	0,089	343,913	-0,913	0,152	305,221	-2,221	0,105	343,4	-0,4	0,184	63
		2	304,353	-1,353	0,091	343,149	-0,149	0,169	308,119	-5,119	0,107	346,801	-3,801	0,22	306,514	-3,514	0,128	345,406	-2,406	0,186	
		3	303,044	-0,044	0,094	341,649	1,351	0,212	305,399	-2,399	0,106	343,974	-0,974	0,168	305,496	-2,496	0,127	343,899	-0,899	0,165	
Test 3	Caldie [1050˚C]	1	306,019	-3,019	0,145	345,663	-2,663	0,127	→						→						53
		2	304,603	-1,603	0,15	345,924	-2,924	0,109													
		3	306,768	-3,768	0,094	345,856	-2,856	0,087													
	Vanadis4E [1050˚C]	1	307,019	-4,019	0,085	346,235	-3,235	0,075	→						→						55
		2	306,615	-3,615	0,061	346,507	-3,507	0,047													
		3	306,808	-3,808	0,062	346,43	-3,43	0,06													

Figure 9 test results

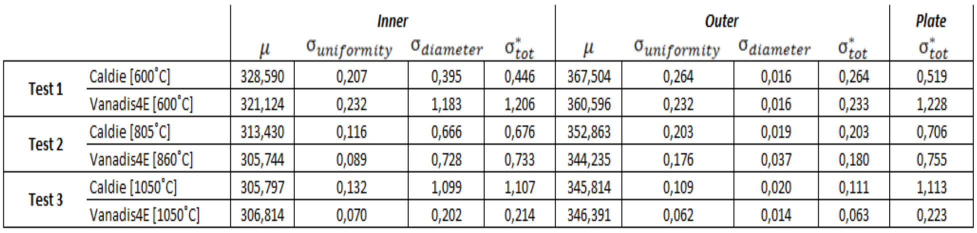
The mean diameter can easily be changed by a different design of the tools and are therefore not a critical variable to observe. The standard deviation however is highly interesting since this value indicates the magnitude of the dimensional unrepeatability which is a major factor regarding processing time. The standard deviation controls the absolute minimum thickness of the plates to ensure that the correct radius is able to be obtained. To prevent more than 6200 defect plates per one million produced, the plate has to have the preferred thickness plus four times the standard deviation(4σ).

To control if the process is meeting the requirements and to select the correct tolerances the Process Capability can be calculated. [3]

$$c_p = \frac{T_{upper} - T_{lower}}{6\sigma^*_{tot}} \tag{9}$$

To reach four sigma the capability of the process has to be: $c_p \geq 1{,}33$. Six Sigma requires: $c_p \geq 2$. [3]

The thickness of a creasing plate is 20mm and diameter deviations measured on the test plates are:



		Inner				Outer				Plate
		μ	$\sigma_{uniformity}$	$\sigma_{diameter}$	σ^*_{tot}	μ	$\sigma_{uniformity}$	$\sigma_{diameter}$	σ^*_{tot}	σ^*_{tot}
Test 1	Caldie [600˚C]	328,590	0,207	0,395	0,446	367,504	0,264	0,016	0,264	0,519
	Vanadis4E [600˚C]	321,124	0,232	1,183	1,206	360,596	0,232	0,016	0,233	1,228
Test 2	Caldie [805˚C]	313,430	0,116	0,666	0,676	352,863	0,203	0,019	0,203	0,706
	Vanadis4E [860˚C]	305,744	0,089	0,728	0,733	344,235	0,176	0,037	0,180	0,755
Test 3	Caldie [1050˚C]	305,797	0,132	1,099	1,107	345,814	0,109	0,020	0,111	1,113
	Vanadis4E [1050˚C]	306,814	0,070	0,202	0,214	346,391	0,062	0,014	0,063	0,223

Figure 10 Measured deviations of test plates´.

To calculate the initial thickness of the plate following calculations can be used.

$$t_{plate} = t_E + \Delta t \tag{10}$$

$$where\ if: r_E + 2\sigma^*_{tot} > r_E$$

$$\Delta t = (r_E + 2\sigma^*_{tot})\sin\left(arccos\left(\frac{r_E}{r_E + 2\sigma^*_{tot}}\cos\left(90 - \frac{\beta}{2}\right)\right)\right) - $$

$$-r_E \sin\left(90 - \frac{\beta}{2}\right) \tag{11}$$

And if: $r_E + 2\sigma^*_{tot_r} \leq r_E$

$$\Delta t = r_E + 2\sigma^*_{tot} - r_E \tag{12}$$

Where:

$r_E =$ expected radius of the plate

$\beta =$ sektor angle of plate

iA smaller radius than expected always requires less additional material then a larger. Therefore it is only necessary to calculate the initial plate thickness for $\mathrm{r_E} + 2\sigma^*_{\mathrm{tot}} > \mathrm{r_E}$.

5.1.1 Example: How to Calculate Thickness of Plate

If the Caldie@600˚C method is used to produce plates with an expected:

(inner radius) $r_E = 150mm$
(thickness) $t_E = 20mm$
(sector angle) $\beta = 60^\circ$
(deviation) $\sigma^*_{tot} = 0{,}4462$

The actual plates will have to have diameters somewhere between

$$300 \pm 4\sigma^*_{tot} = 300 \pm 0{,}4462 * 4 \rightarrow \begin{cases} \emptyset_{max} = 301{,}785 \\ \emptyset_{min} = 298{,}215 \end{cases}$$

with 99.38 percent certainty. To ensure that the correct radius are able to be attained despite the variations, the plates have to have an initial thickness of:

$$t_{plate} = 20 + \Delta t$$

Where

$$\Delta t = (r_E + 2\sigma^*_{tot}) \sin\left(arccos\left(\frac{r_E}{r_E + 2\sigma^*_{tot}} \cos\left(90 - \frac{\beta}{2}\right)\right)\right) -$$

$$-r_E \sin\left(90 - \frac{\beta}{2}\right) =$$

$$= (150 + 2 * 0{,}4462) \sin\left(arccos\left(\frac{150}{150 + 2 * 0{,}4462} \cos\left(90 - \frac{60}{2}\right)\right)\right) -$$

$$-150 \sin\left(90 - \frac{60}{2}\right) = 1{,}033mm \rightarrow$$

$$t_{plate} = 20 + 1{,}033 = 21{,}033$$

---

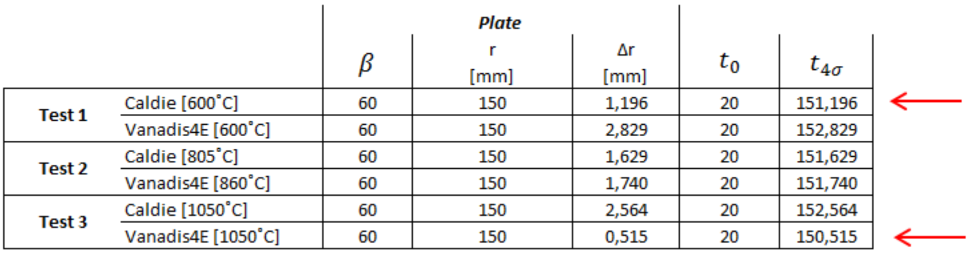
[i] This is shown in appendix A

To check the robustness of the process system, the capability can be calculated.

$$c_p = \frac{T_{upper} - T_{lower}}{6\sigma^*_{tot}} = \frac{301{,}785 - 298{,}215}{6 * 0{,}4462} = 1{,}333 \geq 1{,}33$$

which is a satisfying result.

When using the test results to calculate the needed plated thickness it’s easy to see which method saving most processing time and material.



		β	Plate r [mm]	Δr [mm]	t_0	$t_{4\sigma}$
Test 1	Caldie [600˚C]	60	150	1,196	20	151,196
	Vanadis4E [600˚C]	60	150	2,829	20	152,829
Test 2	Caldie [805˚C]	60	150	1,629	20	151,629
	Vanadis4E [860˚C]	60	150	1,740	20	151,740
Test 3	Caldie [1050˚C]	60	150	2,564	20	152,564
	Vanadis4E [1050˚C]	60	150	0,515	20	150,515

Figure 2 Calculated plate thickness due to measured deviation

5.2 Hardness

The hardness of the plates has to be at least 61 HRC to maintain high abrasive resistance. For Caldie and Vandis4E the plates have to be heated to 1050 ˚C and hold there for a minimum of 30 minutes. The plates then have to be cooled rapidly down to bellow 400 ˚C in less than 280 seconds to attain a hardness of 64 HRC. [1] [12]

The plates heated to 1050 ˚C and hardened only obtained a hardness up to between 50-56 HRC. This probably due to problem with regulation of the temperature in the oven.

		HRC
Test 1	Caldie [600˚C]	63
	Vanadis4E [600˚C]	63
Test 2	Caldie [805˚C]	63
	Vanadis4E [860˚C]	63
Test 3	Caldie [1050˚C]	53
	Vanadis4E [1050˚C]	55

5.3 Result Summery

The test results show that hot forming of Vanadis 4 Extra at 1050˚C where hardening and forming takes place in the same processing step, give raise to the smallest range of deviations with a total standard deviation of $\sigma_{tot}^{*} = 0{,}223\,\mathrm{mm}$. If looking at the processes without hardening, hot forming of Caldie at 600 ˚C seems to be most efficient process with $\sigma_{tot}^{*} = 0{,}519\,\mathrm{mm}$. The surfaces of the plates are satisfying with only a small deformation along the short bended side of the plate, and there doesn't seem to be any tendencies of crack formations. The holes are as expected, oval shaped.

The hardening of the plates, that where heated to 1050 ˚C, where only measured to 53 and 55 HRC unlike the plates that where hardened the conventional way after stress relief and by the ordinary supplier. This plates where measured to 63 HRC. However, the lower hardness of the plates heated to 1050 ˚C is most likely due to not using any protective shield of the plates during heat treatment causing decarbonization of the surfaces combined with bad temperature control of the muffle furnace.

6 Discussion

6.1 Possible further developments of the tool.

The tool can be made in a harder material to prevent dimensional changes of the tool during forming. This could reduce some of the deviations on the outcome. It also would be needed if this method would be realized and the tools had to hold for longer production series. The tool also have to be designed not with the radius of the desired plate, but with a more elliptic form to overcompensate the elliptic/larger radius -form of the pressed plates. Also the pressure on the plate could be changed to test if it could have effect of the result. In this tests there where a lug preventing too much pressure on the plate. This could easily be resolved by either shortening the lugs or making thicker plates.

6.2 Heat treatment

The reason the plates didn't obtain the required hardness may depend on problems with knowing the actual temperature of the plates when being formed. Also the time between furnace and tool could have had a small impact on the result since the plate cools some before it is placed and formed in the tool.

But the most probable explanation is that the furnace is slow in the control of the temperature and therefore raised above the 540˚C it was set for. Annealing at a temperature of 540 ˚C should give the plates a hardness of 61-63 HRC, not 55 HRC which is maintained if heated to 580 ˚C.[1] It is very likely that the temperature climbed over 540 ˚C by 40 ˚C and then stayed there for at least 30 minutes. It takes the oven more than one hour to decline 50 ˚C. Also the lack of protective gas or other surface protections have most likely as well had an impact of the surface hardness.

6.3 Production line

To be efficient this method could be used by pressing larger sheets containing several plates. The sheet could then be processed in an EDM machine and finally cut up to smaller pieces.

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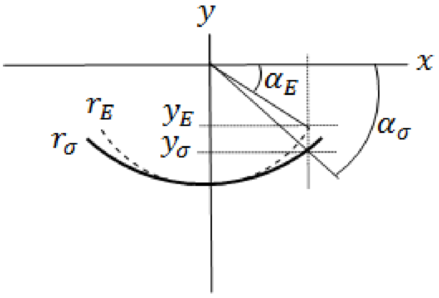
7 Appendices

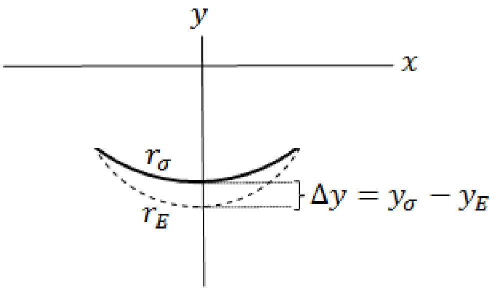
Appendix A – Deviations Calculations
Appendix B – Drawing Lover Tool
Appendix C – Drawing Upper Tool
Appendix D – FEM-Analysis Lower Tool
Appendix E – FEM-Analysis Upper Tool

Appendix A Deviation Calculations

To calculate the extra plate thickness needed to obtain the correct radius due to deviations, the intersection between the two radii has to be found. Knowing the x-value then leads to the angel of the intersection point for the deviation curve. And the y-value can be calculated.

$\boldsymbol{r_\sigma > r_E}$





$$\textit{Expected radius of plate}: \begin{cases} x_E = r_E \cos\alpha_E \\ y_E = r_E \sin\alpha_E \end{cases}$$

$$\textit{Actual radius due to devations}: \begin{cases} x_\sigma = r_\sigma \cos\alpha_\sigma \\ y_\sigma = r_\sigma \sin\alpha_\sigma \end{cases}$$

$$x_E = x_\sigma \rightarrow r_E \cos\alpha_E = r_\sigma \cos\alpha_\sigma \rightarrow \alpha_\sigma = \arccos\left(\frac{r_E}{r_\sigma} cos\alpha_E\right) \rightarrow$$

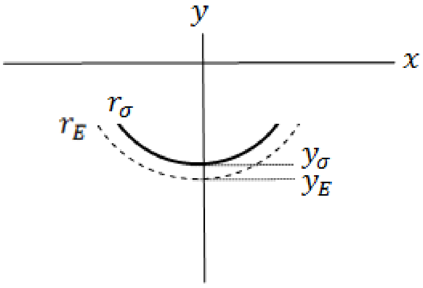
$$y_\sigma = r_\sigma \sin\left(arccos\left(\frac{r_E}{r_\sigma} cos\alpha_E\right)\right)$$

$$\Delta y = y_\sigma - y_E = r_\sigma \sin\left(arccos\left(\frac{r_E}{r_\sigma} cos\alpha_E\right)\right) - r_E \sin\alpha_E = \Delta t$$

$$\left[r_\sigma = r_E + 2\sigma_{tot}^* \quad ; \quad \alpha_E = 90 - \frac{\beta}{2}\right] \rightarrow$$

$$\Delta t = \Delta y = (r_E + 2\sigma_{tot}^*) \sin\left(arccos\left(\frac{r_E}{r_E + 2\sigma_{tot}^*} \cos\left(90 - \frac{\beta}{2}\right)\right)\right) -$$
$$-r_E \sin(90 - \frac{\beta}{2})$$

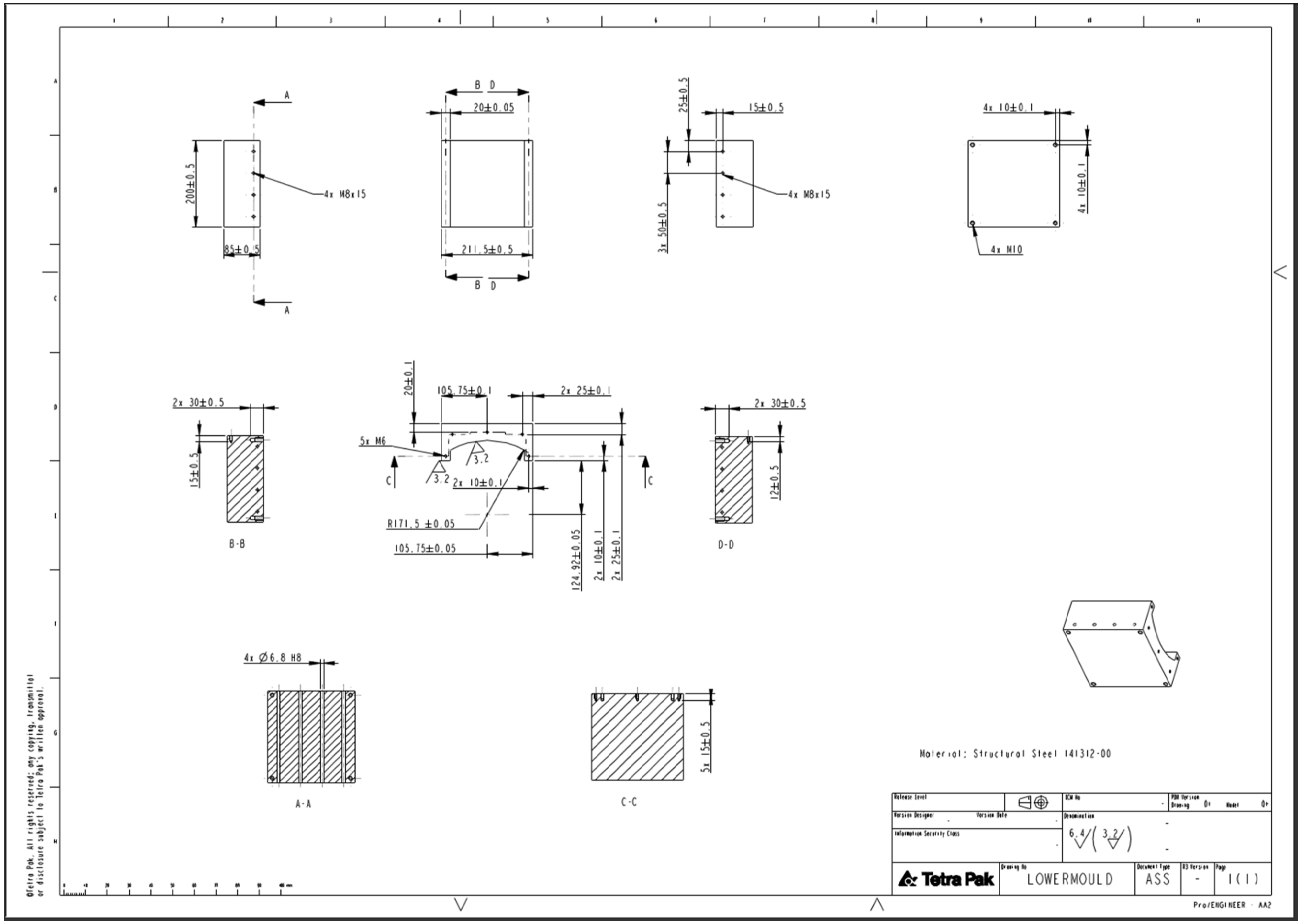
$\boldsymbol{r_\sigma \leq r_E}$



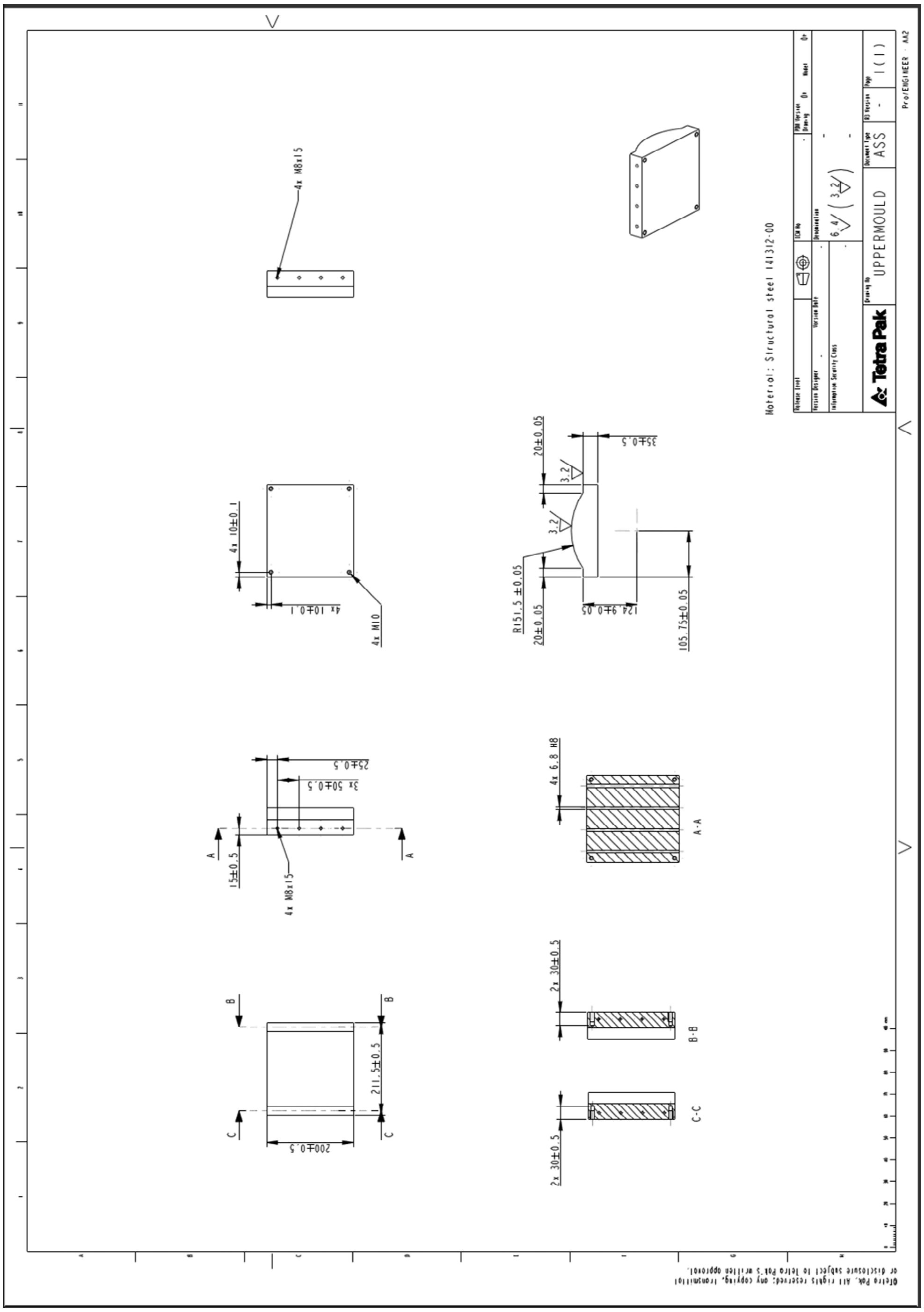
The additional material needed when the actual radius of the plates are larger than the expected, is always equal to the different of the radii.

$$\Delta t = \Delta y_E - \Delta y_\sigma = \Delta r = r_E - r_\sigma$$

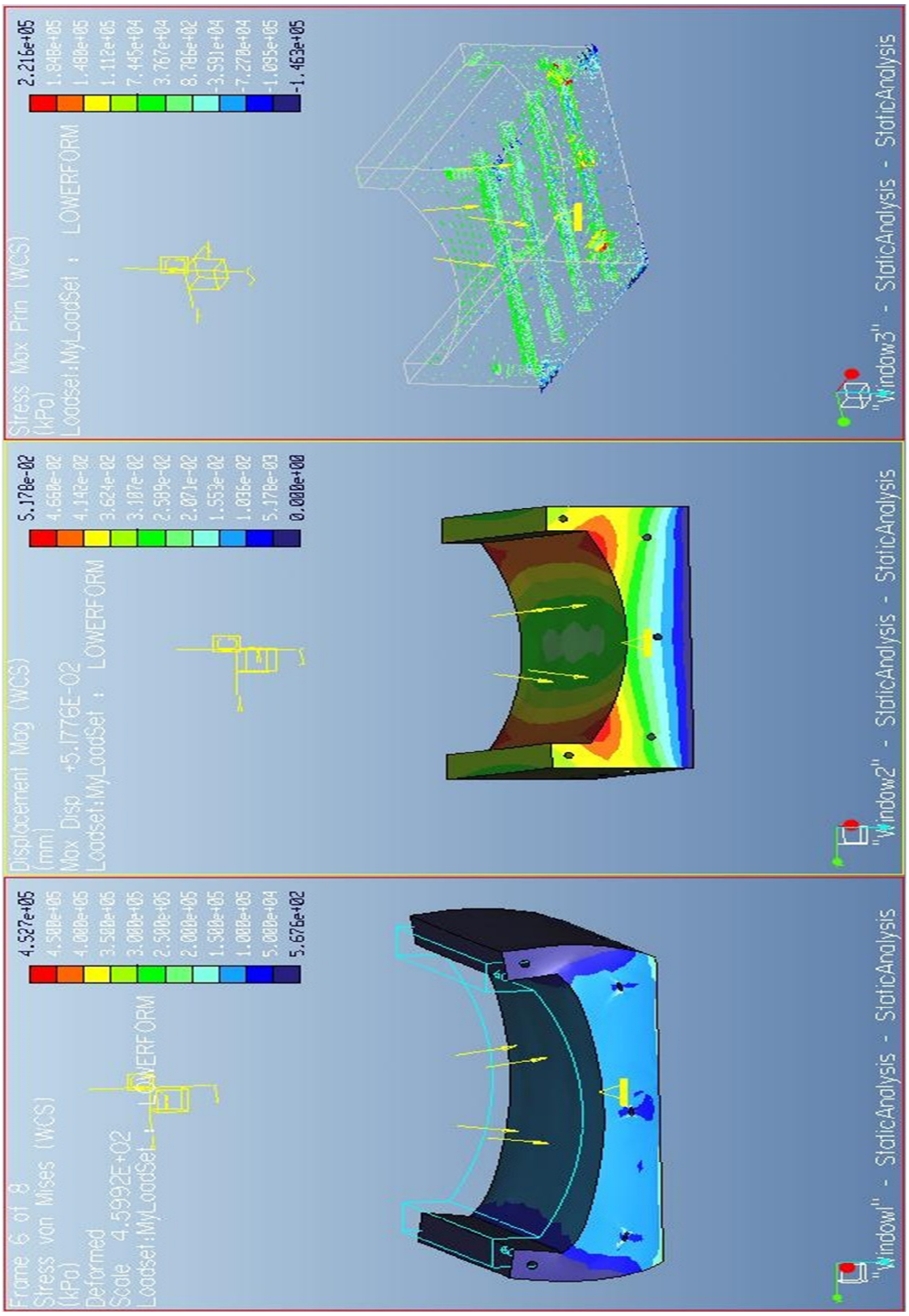
Appendix B Drawing Lower Tool



Appendix C Drawing Upper Tool



Appendix D FEM-Analysis Lower Tool



Appendix E FEM-Analysis Upper Tool