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IMPROVING THE PROCESS EFFICIENCY OF WPC EXTRUSION BY A PRODUCTION LOSS MONITORING SYSTEM

Case: UPM ProFi

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Case: UPM ProFi

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ABSTRACT

This version of the thesis is only partially public due to confidentiality.

This thesis deals with the process efficiency and losses of wood-plastic composite (WPC) extrusion. The study was commissioned by UPM ProFi, which is a WPC manufacturer. It is a subsidiary of UPM-Kymmene Corporation. UPM ProFi has two production mills, one in Finland and the other in Germany. The objective of the thesis was to build a monitoring system for production losses and process efficiency, as well as to detect causes for production losses and to suggest ways to improve the efficiency of WPC extrusion line.

The data used for this study was gathered through written sources related to the industry, WPC conference proceedings, electronic sources and the author's own observations. To determine the level of the process efficiency and the causes of production losses, a monitoring system was built. The monitoring system uses overall equipment effectiveness (OEE) as a process efficiency indicator.

The monitoring system was tested at the beginning of year 2013 in Lahti. In addition, the employees completed a survey dealing with production losses. Earlier, in 2012, another analysis of the production losses was made in Bruchsal. The results of these and the author's own observations were used as background information for suggestions for further development.

One of the key outcomes of the study was the monitoring system with which process efficiency and production losses can be monitored. During the test period the average OEE was X %. The main reasons for the low process efficiency were raw material and equipment failures. The findings of the survey also supported this result.

The development suggestions are divided into raw material, employees' attitude and knowledge, maintenance and continuous improvement. Concrete measures for improving the process are presented in each of these areas.

Key words: wood-plastic composite, OEE, extrusion, process efficiency, UPM ProFi, monitoring system

Lahden ammattikorkeakoulu
Muovitekniikan koulutusohjelma

LANGE, HERMAN: Puumuovikomposiittiekstruusion tuotantotehokkuuden parantaminen hävikin seurantajärjestelmän avulla Case: UPM ProFi

Muovitekniikan opinnäytetyö, 54 sivua, 27 liitesivua

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TIIVISTELMÄ

Tämä versio opinnäytetyöstä on vain osittain julkinen luottamuksellisen tiedon vuoksi.

Tämän opinnäytetyön aihe on puumuovikomposiittiekstruusion tuotantotehokkuus ja -hävikki. Työn toimeksiantaja on UPM ProFi, joka on puumuovikomposiittituotteiden valmistaja. Yhtiö on osa suomalaista UPM-Kymmene Oyj:tä. UPM ProFin kaksi tuotantolaitosta sijaitsevat Suomessa ja Saksassa. Hävikin ja tuotantotehokkuuden seurantajärjestelmä, syyt hävikin syntymiselle sekä ekstruusiolinjan tehokkuuden kehittäminen ovat keskeisiä aiheita tässä työssä.

Tutkimuksen aineisto koostuu alaa koskevista kirjallisista ja sähköisistä lähteistä, alan muista julkaisuista sekä tekijän omasta havainnoinnista. Tuotantotehokkuuden ja hävikin syiden määrittämiseksi työssä rakennetaan hävikinseurantajärjestelmä. Seurantajärjestelmässä käytetään KNL-laskentaa (käytettävyys, nopeus, laatu) tuotantotehokkuuden mittarina.

Seurantajärjestelmää kokeiltiin Lahdessa alkuvuonna 2013. Lisäksi työntekijät vastasivat kyselyyn, joka koski tuotantohävikin syitä. Aikaisemmin vuonna 2012 Bruchsalissa toteutettiin toisenlainen tuotannonseuranta. Näiden tulosten lisäksi tekijän omaa havainnointia käytettiin kehitysehdotusten pohjana.

Yksi työn tuotoksista oli seurantajärjestelmä, jolla tuotantotehokkuutta ja tuotantohävikkiä voi valvoa. Kokeilujakson aikaisen KNL-mittauksen tulos oli X %. Suurimmat hävikin aiheuttajat olivat raaka-aine ja laiteviat. Myös kyselyn tulokset tukivat tätä havaintoa.

Kehitysehdotukset on jaettu raaka-aineeseen, työntekijöiden asenteeseen ja tietotaitoon, kunnossapitoon sekä jatkuvaan parantamiseen. Jokaisesta näistä on esitelty konkreettisia toimia prosessin kehittämiseksi.

Asiasanat: puumuovikomposiitti, KNL, ekstruusio, tuotantotehokkuus, UPM ProFi, tuotannonseurantajärjestelmä

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Verbesserung des Prozesseffizient der WPC Extrusion mit der Hilfe des Verlustüberwachungssystems
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ABSTRACT

Diese Version der Arbeit ist nur teilweise öffentlich wegen der Vertraulichkeit.

Das Thema dieser Bachelorarbeit ist die Prozesseffizienz und die Produktionsverluste in Rahmen der Extrusion des Holz-Kunststoff-Verbundmaterials (WPC). Der Auftraggeber ist UPM ProFi, die Produkte von WPC herstellt. Sie ist eine Tochtergesellschaft von UPM-Kymmene Oyj. UPM ProFi hat zwei Werke, eine in Finnland und eine in Deutschland. Das Überwachungsystem für die Verlust und Prozesseffizient, die Gründe der Verluste und die Entwicklung der Prozesseffizient der Extrusionlinie sind die Hauptthemen der Arbeit.

Die Daten der Arbeit bestehen aus den Büchern und Tagungsbänden in Bezug auf die Industrie, elektronische Quellen und eigene Beobachtungen des Autors. Um die Gründe der Verluste und die Prozesseffizient zu definieren wird ein Verlustüberwachungssystem gebaut. In dem Überwachungssystem wird das GAE-Rechenverfahren (Gesamtlageneffektivität) als Meter der Prozesseffizient benutzt.

Dieses Überwachungssystem wurde in Lahti Anfang des Jahres 2013 ausprobiert. Außerdem haben die Arbeiter eine Anfrage, die die Gründe der Produktionsverluste befasst, beantwortet. Früher in dem Jahr 2012 wurde in Bruchsal eine andersartige Produktionsüberwachung durchgeführt. Zu diesen Resultaten wurde noch die eigene Beobachtungen des Autors als Grundlage für die Entwicklungsvorschläge benutzt.

Ein Ergebnis der Arbeit war das Überwachungssystem, womit man die Prozesseffizient und die Verluste überwachen kann. In der Testperiode war das Resultat der GAE-Messung X %. Die größten Ursachen für den Verlust waren der Hauptrohstoff und die Maschinenfehler. Auch die Resultate der Anfrage haben diese Beobachtung bekräftigt.

Die Entwicklungsvorschläge sind in dem Hauptrohstoff, der Einstellung und dem Wissenstand der Arbeiter, der Instandhaltung und der kontinuierliche Verbesserung geteilt. Für jeden von diesen hat man konkrete Operationen um den Prozess zu entwickeln vorgestellt.

Schlüsselwörter: Holz-Kunststoff-Verbundmaterial, GAE, Extrusion, Prozesseffizienz, UPM ProFi, Überwachungssystem

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1 INTRODUCTION

Process efficiency is an important factor in making the operation of a business profitable. Briefly put, process efficiency means the ability to produce good products by using resources as little as possible. Efficient production can be achieved by producing a product at the lowest cost possible. (Investopedia 2013.) Overall equipment effectiveness (OEE) is a tool to measure the process efficiency of factories, machines, equipment, etc. The OEE is divided into three factors. These are availability, performance and quality. According to researches, the average OEE in the manufacturing industry is approximately 60 %, which means that 60 % of the production capacity is being utilized (Novotek 2012). 85 % or more is considered the world class level of OEE (Novotek 2012).

UPM ProFi is a wood-plastic composite (WPC) manufacturer that has mills in Lahti, Finland, and in Bruchsal, Germany. Composite is a combination of materials in which two or more materials are combined in a way that the materials are not being dissolved or merged together (Saarela, Airasmaa, Kokko, Skrifvars & Komppa 2007, 454). From WPC, UPM ProFi produces profiles for outdoor living. Such products are, for example, decking boards which are made by extrusion. That is a plastic processing method and one part of the UPM ProFi manufacturing process. In other words, UPM ProFi produces both WPC and finished WPC profiles.

Since UPM ProFi was established it has aimed at producing and delivering high quality products with high process efficiency. Nevertheless, there is still a great demand for improvement in order to achieve this goal. During my internship in Bruchsal Mill in summer 2012, I also got to observe the problems in practice. In 2012 UPM ProFi produced a total of X tons of WPC of which X tons were acceptable products (UPM ProFi 2013d). That means that X % of the composite was discarded. In Lahti Mill the share of discarded composite was X % and in Bruchsal Mill it was X % (UPM ProFi 2013d).

1.1 Objectives of the study

Extrusion is a plastic processing method and one part of the manufacturing process of UPM ProFi. As for extrusion, this thesis has three objectives, which are: to build a monitoring system for production losses and process efficiency, to determine the major causes of the production losses and to make development suggestions to increase process efficiency.

The objective of the theoretical part of the thesis is to give background information about the process related to my study. The theoretical part discusses the theories of WPC, extrusion, and OEE.

Research problems comprise the following questions:

- How could the process efficiency of extrusion be determined?
- Why is the process efficiency of the extrusion in UPM ProFi mills low?
- How could process efficiency be improved?

1.2 Limitations

The theory part of this study is limited to WPC, extrusion, and OEE. The theory of WPC focuses especially on wood-thermoplastic composites and their composition, processing methods and properties. The theory part on extrusion concentrates on the process in general and the twin screw extrusion which UPM ProFi uses in its manufacturing process. In the theory part of this thesis also the extrusion method and the WPC of the case company will be presented in order to explain the background of the commission. For the same reason the OEE method will be introduced in that part.

The results of this study are also useful for the other extrusion lines of UPM ProFi in Bruchsal Mill and in Lahti Mill because most of them are almost identical to Extruder 2 in Lahti Mill. There are a few different kinds of extruders but they all function almost in the same way. The same material can be applied as well.

1.3 Research methods

The theory part is based on written sources of the industry, WPC conference proceedings and electronic sources. The written sources deal with WPC and extrusion. The information about the company has been collected from the homepage and the intranet of UPM ProFi. I have gained information about the manufacturing process through my own observations during my internship in Bruchsal in summer 2012. Also Jouko Pussi, Mill Manager, was interviewed for some details of the process.

To determine the OEE and the causes of production losses a production loss monitoring system was built. The data for the system was collected through paper monitoring forms. Also the KPI (key performance indicator) report of UPM ProFi was used to gather data for the system. The reasons for the production losses were marked down in the monitoring form. The data for the monitoring system was collected from Extruder 2 in Lahti between 22nd January 2013 and 7th February 2013.

In Bruchsal the material loss analysis was made periodically in autumn 2012 in order to determine the major defects of the rejected products and the major causes of these defects. This information was also used as support for this study. In addition, a survey was carried out with the employees to determine the reasons for the losses.

After the data acquisition the reasons and development suggestions were discussed with the mill management.

2 COMPANY PROFILE

UPM ProFi is a WPC manufacturer. It is a subsidiary of UPM-Kymmene Corporation which is a Finnish forestry company. The corporation's turnover is about 10 billion euros and it has approximately 22 000 employees worldwide (UPM-Kymmene Oyj 2013). It is divided into three different business groups which are Paper, Energy and Pulp and Engineered Materials (UPM-Kymmene Oyj 2012). UPM ProFi is a part of Engineered Materials.

UPM ProFi produces WPC products which are made of their own UPM ProFi composite. The composite is made from label waste, matrix plastic and additives. This label waste is waste from the production of UPM Raflatac, which is a labelstock manufacturer.

UPM ProFi has two production mills: one in Lahti, Finland, and the other in Bruchsal, Germany. The Lahti Mill is smaller; it has three production lines and 17 employees. The mill in Bruchsal has 8 production lines and 39 employees. (UPM ProFi 2013a.)

2.1 Manufacturing process of UPM ProFi

2.2 Products of UPM ProFi

UPM ProFi's main product is UPM ProFi Deck. One complete product family has been developed around the deck. That is presented in Figure 2.

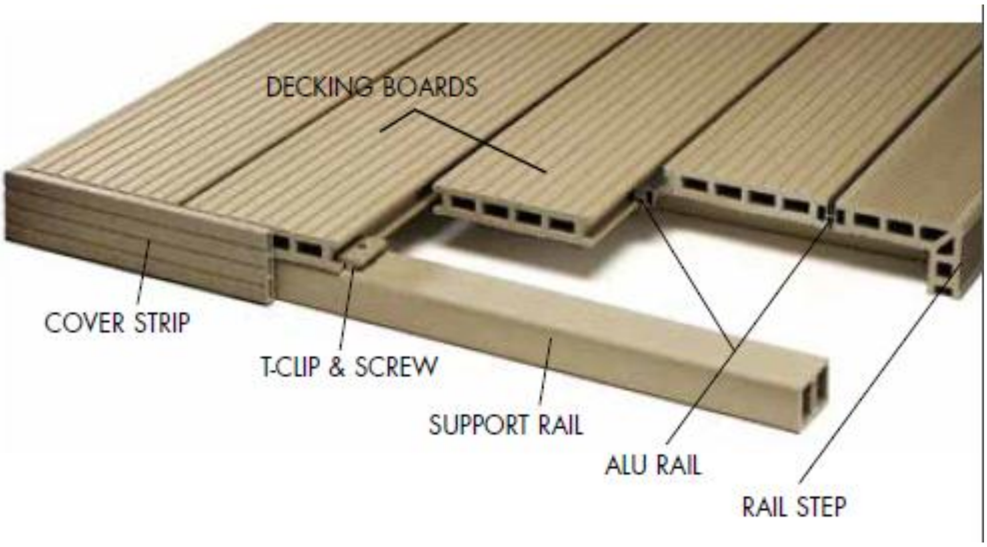

FIGURE 1. Product family of UPM ProFi Deck (UPM ProFi 2013b)

These products are made from the same polypropylene-based UPM ProFi WPC, which will be presented in more detail in Chapter 3.1.4. The Alu Rail is an exception to this as it is an aluminium part produced by a subcontractor.

Deck is a decking board for outdoor areas, such as terraces and balconies. Rail Step is a product of which stairways can be built or it can also be used as cover for the end of terraces just like Cover Strip. These products are made by extrusion, which will be discussed in Chapter 4. T-Clip is a small installation part which is made by injection moulding. The product family is available in four dark colours and in three light colours.

In addition, UPM ProFi manufactures products called UPM ProFi Facade and Patio. Facade is an exterior cladding product which is also made from the same WPC as Deck. Also for Facade is made some installation parts are made by injection moulding. Patio is also a decking board for outdoors. It differs from Deck by having a different matrix plastic. In Patio recycled polyethylene is used as matrix plastic. Patio is available only in dark colours.

3 WOOD-PLASTIC COMPOSITE

Wood-plastic composite, simply referred to as WPC, is a combination of some form of wood and plastic. Plastics can be either thermosets, which once cured cannot be melted by reheating, or thermoplastics, which can be melted and formed again and again. (Clemons 2002, 10.) Traditionally the plastic industry has used glass fibres in order to reinforce plastics. The history of wood reinforced plastics dates back to the early 20th century when chemist Leo H. Baekeland invented Bakelite which is a compound of synthetic resin and wood-flour (Kulju 1965, 44). Although in Europe wood-thermoplastic composites were produced much earlier, the major growth happened in the United States in the 1980s and 1990s (Caufield, Clemons, Jacobsen & Rowell 2005, 366). In Europe the industry has started to grow in the 2000s (Nash 2011). This study focuses on wood-thermoplastic composites.

3.1 Wood-thermoplastic composites

3.1.1 Materials

As stated above, the wood-particle of WPC can be found in many forms. Commonly the wood-fibres are used as wood flour or as short fibres. Also long fibres, wood-pulp fibres and paper are used in WPC. (Clemons 2002, 12; Caufield et. al 2005, 367.) Wood flour has comparatively high bulk density and free-flowing nature. The cost of wood flour is relatively low and its familiarity and availability attracts WPC manufacturers and users. Using wood fibres instead of flour increases mechanical properties like strength, elongation and unnotched impact strength. What must also be taken into consideration is that using fibres causes processing difficulties in feeding and in metering because of their low bulk density. (Caufield et. al 2005, 367.) The amount of wood in WPC wood varies between 30 and 85 Wt% (Koto, Tiisala 2004, 1).

The biggest limitation when processing WPCs is the processing temperature because the thermal stability of wood is limited (Caufield et. al 2005, 370). Generally, only thermoplastics that can be processed at temperatures below 220°C are used in WPCs (Koto & Tiisala 2004, 1). Typical matrix thermoplastics are polyethylene (PE) polypropylene (PP) and polyvinylchloride (PVC). Also polystyrene (PS) and acrylonitrile-butadiene-styrene (ABS) are being used. (Caufield et. al 2005, 370.) Table 1 (p. 10) presents the comparison of the processing and usage features of the three main matrix thermoplastics.

TABLE 1. Comparison of the main WPC matrix materials (adapted from: Kretschmer, Radovanovic, Grüneberg, Mai & Militz 2007, 20-24)

Polymer	Processing features	Usage features
PE-HD	- Processing temperature: 160 - 200 °C - Good oxidation stability, when melted - Not abrasive or corrosive - Predrying not necessary - Good processibility in WPC - Good gliding properties	- Usage temperature: -50 - 90 °C - Semi-crystalline, non-polar (coupling agent necessary) - Low density: 0.94-0.97 g/cm^3 - High ultimate elongation and toughness - Low water absorption - Permeable to water - Good weldability - Good oxidation stability - Poor flame resistance - Embrittling in longer light influence
PP	- Processing temperature: 170 – 220 °C - Good oxidation stability, when melted - Not abrasive or corrosive - Predrying not necessary - Good processibility in WPC - Poorer gliding properties than PE	- Usage temperature to 110 °C - Semi-crystalline, non-polar (coupling agent necessary) - Low density: 0.91 g/cm^3 - Clearly greater stiffness than PE-HD - Good weldability - Low water absorption - Low impact strength below 0 °C - Poor weather resistance - Poor flame resistantce
PVC-U	- Maximum processing temperature: ca. 190 °C - Poor oxidation stability when melted - Predrying not necessary - Dissociation of HCl possible => corrosion	- Usage temperature ca. -5 – 60 °C - Amorphous, polar (coupling agent not necessary) - Good weldability - Good chemical resistance - Decent strength - Good flame resistantce - Permeable to water - Good weather resistance

Materials used in WPCs are not limited to wood and thermoplastic only. There are also additives added in small amounts to improve the process and the features of the end-products. Such additives for WPC are listed in Table 2 (p. 12)

TABLE 2. (Adapted from Kretschmer et. al 2007, 25-30; Poikelispää 2004, 25-26; Ochs 2001, 647)

Additive	**Function**	**Effect**
Coupling agents	- Improves adhesion between wood and plastic	- Better mechanical properties - Lower water absorption - Better dispersion - Higher dimension stability
Lubricants	- Lubricates the material externally and internally	- Lower viscosity and better flowing properties - Regulation of adhesion between machine surfaces and material - Lower tool pressure - Higher output
Thermal stabilizers	- Prevents or decelerates the decomposition of polymers at processing	- Affects against thermal oxidative decomposition and discolouration during the process
UV stabilizers	- Absorbs UV radiation	- Prevents embrittlement and discolouration
Colourants	- Colours the material to the core	- Desired colour => Better aesthetics - UV protection (TiO_2, soot)
Flame retardants	- Absorbs the heat - Creates a non-flammable charring or a non-flammable surface layer	- Diminishes the materials ignition - Reduces smoke and gases when the material is burning
Biocides	- Microbiostatic activity inhibits the reproduction of the microorganisms or microbicidal activity kills the microorganisms	- Prevents microbial growth on material or exterminates the growth from the material
Foaming agents	- Chemical: in specific temperature the agent absolves gas, which foams the material - Physical: gases (CO_2, N_2) are mixed to the melted material	- Lower weight - Lower material feeding input - Better thermal and sound insulation - Fewer sinks and warpage appearances

3.1.2 Processing

The manufacture of WPC is often a two-step process. First the raw materials are mixed together in the compounding process and then this compounded material is formed into a product. The compounding is made either in a batch or in a continuous mixer. The process can also be a one-step process, where the compounding is made by the extruder in which the actual product is made.

Mostly, WPC products are manufactured by extrusion. Also other manufacturing methods like injection moulding, calendering, thermoforming and compression moulding are used for WPC. (Caufield et. al 2005, 370.)

Even though the processing methods for WPC are the same as for traditional thermoplastic products, there are some specific problems when processing WPC, which is because of the bulk density, moisture content or viscosity of WPC. For instance the moisture content of normal constructional wood is about 5-7%. Damp fibres occlude machines and hoses, decrease products' surface quality, make holes in the material and weaken the mechanical properties. For example, when using a twin screw extruder the moisture content of the fibres has to be less than 1 %. (Koto & Tiisala 2004, 3;5.)

3.1.3 Properties

WPC combines the properties of wood and plastic. The properties depend on what kind of plastic and wood is compounded together and what their relation is. Some of the properties can be controlled by using additives. Table 3 (p. 14) shows the comparison of the strength properties of different relations of wood, plastic and coupling agent. (Caufield et. al 2005, 367.)

TABLE 3. Mechanical properties of aspen fibre-polypropylene composites (Caufield et. al 2005, 372)

Specimen	Flexural Strength (MPa)	Flexural Modulus (GPa)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Izod Notched (J/m)	Izod Unnotched (J/m)
PP	27.9	1.38	26.2	1.69	22.4	713.5
PP/MAPP	34.6	1.79	29.3	1.82	18.6	563.3
30A/70PP	49.5	4.12	29.3	4.52	24.8	101.7
30A/68PP/MAPP	60.2	3.82	44.9	4.10	21.1	128.3
40A/60PP	54.6	4.60	34.9	5.22	19.6	85.5
40A/58PP/MAPP	66.4	4.66	47.7	5.14	19.8	108.7
50A/50PP	50.2	5.48	28.4	5.81	26.4	67.1
50A/48PP/MAPP	75.7	5.88	53.1	6.68	21.9	98.5
60A/40PP	45.9	6.09	25.6	6.95	23.9	55.2
60A/38PP/MAPP	75.8	6.73	48.1	7.19	21.3	81.1

In Table 3 it can be seen that the more the amount of aspen fibres increases, the more flexural strength and modulus and also tensile modulus increases in accordance with another. Furthermore, by adding 2 % MAPP the strengths tend to grow. MAPP (maleic anhydride grafted polypropylene) is a typical coupling agent for WPC (Caufield et. al 2005, 368). In Table 3 it is also shown that as the wood content increases the impact strength of unnotched composite (Izod Unnotched) decreases.

WPCs absorb less moisture and more slowly way than normal wood. Therefore they have better fungal resistance and dimensional stability when exposed to moisture. Composites with high wood content have lower fungal resistance, which is why fungicides are often added in them. (Caufield et. al 2005, 374.)

Generally, WPC products can be processed with woodworking machines. However, when processing, the surface of the composite gets damaged, which results in wood fibres getting exposed to moisture more easily. Also plastic machining methods, like welding and thermoforming, can be applied to WPC. When welding, the strength of the weld depends on the relative wood content. (Koto & Tiisala 2004; Tangram Technology Ltd. 2002.)

Like thermoplastic in general, also wood-thermoplastic composites are relatively easy to recycle into new products. At the end of WPC’s life cycle it can be completely burned to energy at waste incineration plants unlike traditional glass fibre-plastic composites in which the glass does not burn.

3.1.4 UPM ProFi wood-plastic composite

4 EXTRUSION

Extrusion is a method where material is shaped through an extrusion tool or die (in this study a tool is used) in a continuous process into a product of the desired shape. Profiles, pipes, films, bars and cables are product examples of extrusion. (Vienamo & Nykänen 2013.) The majority, approximately 60 %, of thermoplastics are processed by extrusion (Seppälä 2008, 261). The actual extrusion line can be divided into following elements:

- Extruder
- Tool
- Calibration
- Cooling
- Pulling devices
- Cutting
- Finishing and packing

(Vienamo & Nykänen 2013)

Furthermore, a flow chart of an extrusion line is shown in the following Figure 4.

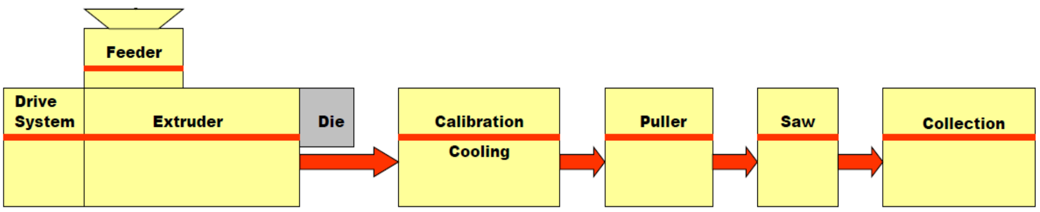

FIGURE 2. Flow chart of an extrusion line (Jones 2011)

Both the list assembled in accordance with Vienamo and Nykänen (2013) and Figure 4 after that help to comprehend the structure of the extrusion line and the measures of its different stages. The functions of these elements are presented further in this chapter (pp. 19-20) as the material flow through the extrusion line will be dealt with in a more detailed way.

As the two demonstrations previously (p. 17) show, the extruder itself is included in the first stage of the extrusion line. Extruders have various types of parts, which are listed below:

- Motor
- Transmission
- Screw
- Barrel
- Feed hopper
- Heaters
- Coolers

(adapted from Seppälä 2008, 263)

The motor of the extruder generates force, which rotates the screw. The force is transferred to the screw by transmission. The extruder screw is the most important and valuable part of the extruder. It is shown in Figure 5.

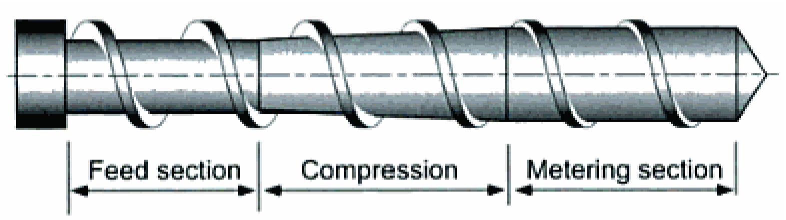

FIGURE 3. Screw geometry of conventional extruder screw (Rauwendaal 2001, 12)

The three main geometrical sections of the screws are feed, compression and metering section, which are seen in Figure 5. In addition to these, decompression, degassing and mixing sections are also often used (Rauwendaal 2001, 363; 464). The choice of the sections used depends on the manufactured application.

In extrusion, material is fed with a hopper to a barrel where the screw is rotating. There the frictional forces in the material and on the surfaces of both the barrel and the screw convey the material forward. This continues at least as long as the material is in the solid state below its melting point. As the material moves forward it gets heated up as a result of viscous shear heating and because of the heat conducted from the barrel heaters. (Rauwendaal 2001, 12-13; Giles, Wagner & Mount 2005, 39.) Shear heat is divided into external and internal heat generation. In the case of external heat generation the screw moves the material so that it scrapes the surface of the barrel. This generates frictional heat. In the case of internal heat generation, the individual plastic layers scrape each other and in this way generate viscous heat. (Giles et. al 2005, 39.)

When the temperature of the material reaches the melting point, a melt is formed on the surface of the barrel. At this point the conveying zone of solid material ends and the plasticizing zone starts. Also the compression section may begin at this point, but generally it is not necessarily a direct consequence. The so-called boundaries of the functional zones can change as the operating conditions change. This is due to the polymer properties and the screw geometry. As the material is transported forward, the solid material melts until all of it is melted. After that the plasticizing zone has ended and the melt conveying zone starts. In this zone the melt material is simply pumped into the tool. (Rauwendaal 2001. 13.)

As the material flows through the tool, it adopts the shape of the flow channel of the tool. Thus, when the material leaves the tool its shape will more or less correspond to the cross-sectional form of the final portion of the flow channel. (Rauwendaal 2001, 13.) The form of the extrudate swells after flowing out of the tool (Giles et. al 2005, 6). This is illustrated below in Figure 6.

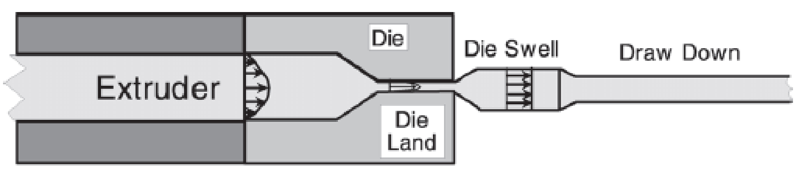

FIGURE 4. Die swell and draw down (Giles et. al 2005, 6)

The swell is drawn down by pulling the extrudate with a puller. From the tool the extrudate is pulled to the cooling stage. It can be quenched with water, air and cooling rolls. Profile extrudates are commonly cooled in tanks filled with water. In some cases the tanks are connected to vacuum systems. (Giles et. al 2005, 6.) Furthermore, between the tool and the water tank a specific calibration tool can be used to cool the material and to calibrate the extrudate to the desired cross-sectional form.

After the cooling the extrudate is pulled and cut. Also the pulling and the cutting applications depend on the type of the extrudate. After the extrudate is cut it is packed and delivered to customers.

4.1 Twin screw extrusion

In twin screw extrusion there are two screws set side by side inside the barrel. There are many types of twin screw extruders on the market. The one to use depends on the application produced. (Giles et. al 2005, 95.) The twin screw extruders can be classified on the basis of the rotation direction and the position in relation to each other. This is demonstrated in Figure 7 (p. 21).

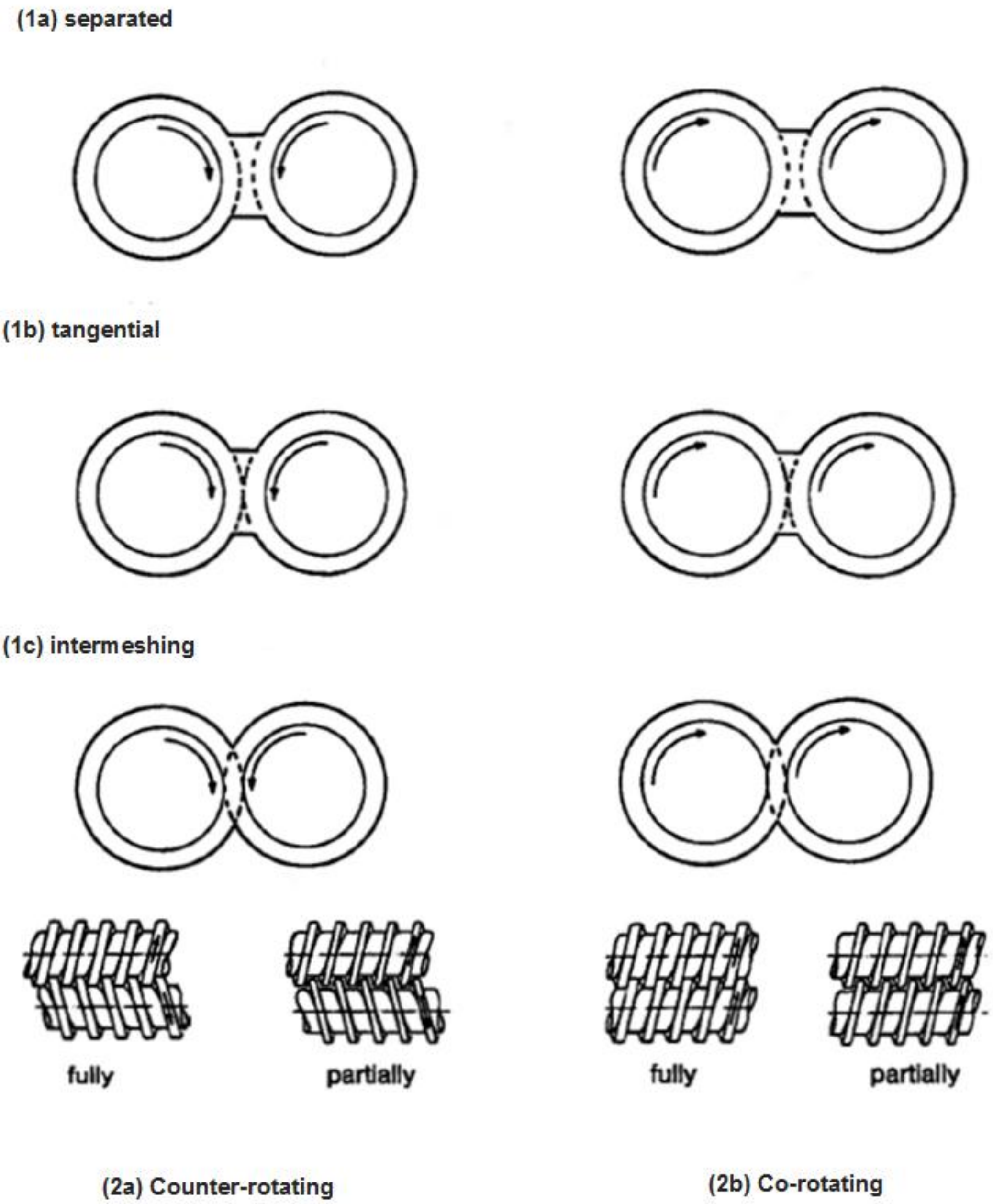

FIGURE 5. Classification of non-intermeshing ((1a) and (1b)) and intermeshing (1c) and classification of counter-rotating (2a) and co-rotating (2b) screws (White & Kim, 2010, 8)

If the screws are rotating in the same direction they are called co-rotating and if they are rotating in the opposite direction they are called counter-rotating. The screws are also classified on the basis of the distance to each other. If the centerline distance between the shafts is less than the screw diameter the screws are called intermeshing. (Giles et. al 2005, 95.) This is also demonstrated in

Figure 7. Furthermore, the intermeshing screws can be either fully or partially intermeshing (White & Kim 2010, 8). If the centerline distance between the shafts is greater than or equal to the screw diameter the screws are called non-intermeshing (Giles et. al 2005, 95).

The geometry of the screws is either parallel or conical. The conical screws taper from the feed section to the tip of the screws. (Giles et. al 2005, 95.) Figure 8 shows examples of both parallel and conical screws.

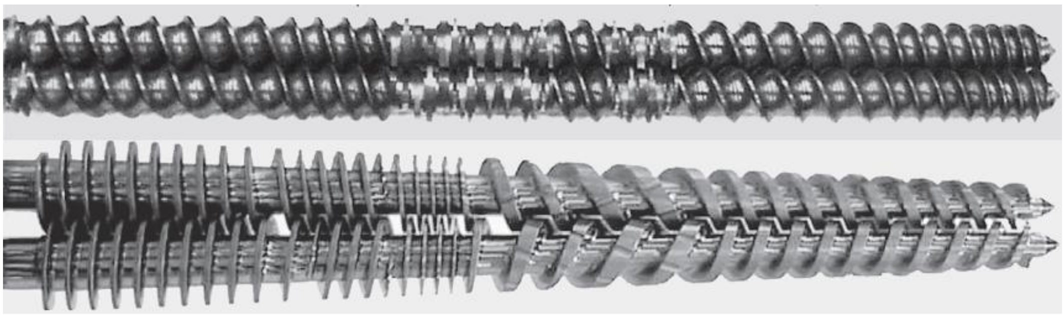

FIGURE 6. Example of parallel (upper) and conical (lower) twin screw extruder screws (adapted from Giles et. al 2005, 95, 122)

Typically the conical screws are counter-rotating and intermeshing. Parallel screws are met in all options. Only the co-rotating intermeshing parallel screw extruders are not used in practice. (Giles, Wagner, Mount 2005, 95.)

4.2 Extrusion at UPM ProFi

5 OVERALL EQUIPMENT EFFECTIVENESS

OEE (Overall Equipment Effectiveness) is a characteristic number to describe production efficiency. This number combines three factors for production loss. These factors are availability, performance and quality. Availability, or uptime rate, demonstrates the production loss which is caused by machine stoppages. Performance rate reveals the speed loss which occurs when the machine runs at a slower speed than what would be its maximum speed. The quality rate represents the share of waste production. The OEE is a product of these three rates. (Novotek 2012.)

$$OEE = Availability * Performance * Quality$$

Figure 9 presents the structure of OEE.

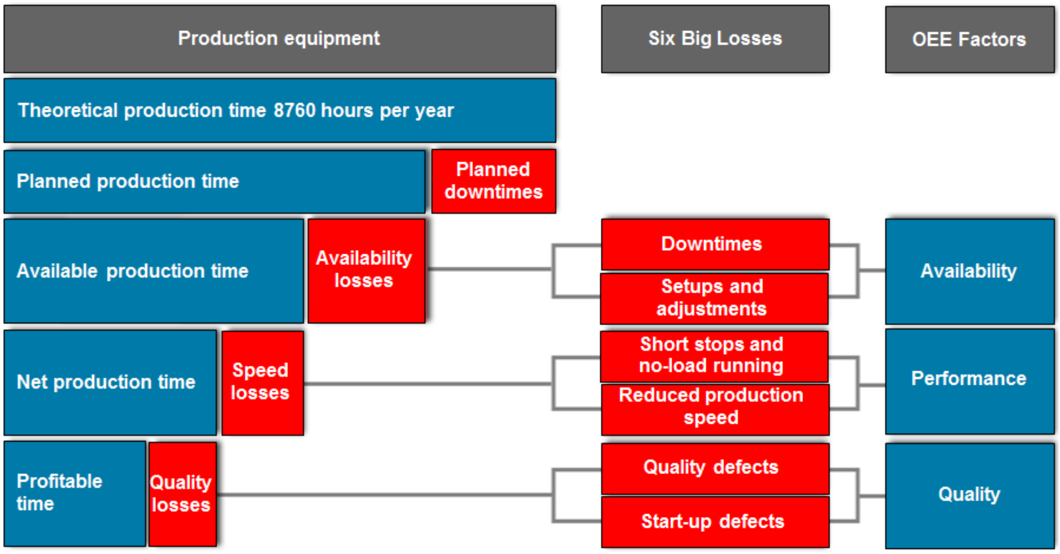

FIGURE 7. Structure of OEE (adapted from Fastems Oy Ab 2011)

In Figure 9 the planned production time means the time that the operating machine is supposed to run. When the machine is available to run, the time is called available production time, which means that the downtime is subtracted from the planned production time. The net production time can be considered as the time in which the machine could produce products at full speed. The profitable time means the time in which the machine could produce accepted products at full speed.

In order to achieve the OEE of 100 %, the measured machine has to work at full speed during the available production time and produce good quality products only. The world class OEE is defined to amount to 85 % (Novotek 2012). To achieve this average rate of availability, performance and quality should amount to approximately 95 %. In Figure 9 (p. 24) the Six Big Losses of production are also presented. Some examples of those losses are listed in Table 4.

TABLE 4. Six Big Losses and examples of them (adapted from Novotek 2012)

Six Big losses	**Examples**
Downtime	• Device breakdowns • Unexpected maintenance tasks • Breakdown of tools • Other system failures
Setups and adjustments	• Product changes • Material shortage • Cleanings • Adjustment actions • Start-ups
Short stops and no-load running	• Congestion situations • Raw material problems • Feeding problems • Momentary undercapacity of dispatching department
Reduced production speed	• Overloading of the process • Incorrect adjustments • Worn-out equipment • Inefficiency of the process employees
Quality defects	• Production that does not fill the quality criterion • Production that needs repairing
Start-up defects	• Loss and over production at start-ups

5.1 Availability

The availability factor takes into account all the occurrences which stop the planned production for some time. These losses are called downtime losses. Production time equals the available production time deducted by the downtime. The availability rate is calculated by the following formula:

$$Availability = \frac{Production\ time}{Available\ production\ time}$$

The reasons for the downtime can be, for example, machine failures, proactive maintenance tasks, or some actions related to settings. Although usually it is not possible to eliminate the downtime completely, it can be shortened significantly. (Novotek 2012.)

5.2 Performance

Performance factor takes into account losses which are caused by using lower production speed than what would be the maximum or ideal production speed. The performance rate can be calculated in two ways depending on the manufactured product. These formulas are:

$$Performance = \frac{Total\ production}{Maximum\ production\ speed * Production\ time}$$

$$Performance = \frac{Ideal\ cycle\ time}{Real\ cycle\ time}$$

The reasons of the performance losses are, for example, worn-out machines, low-quality raw material or ineffective machine operator. (Novotek 2012.)

5.3 Quality

Quality factor represents the losses which are caused by poor quality. The production that does not fit in to the frame of the quality tolerances is comprehended as quality loss. It is calculated on the following way:

$$Quality = \frac{Approved\ production}{Total\ production}$$

Quality losses are results of for example rejected production caused by manufacturing defects or production that is graded to lower quality class. (Novotek 2012.)

6 DATA ACQUISITION

6.1 Production loss monitoring system

6.2 Material loss analysis in Bruchsal Mill

6.3 Survey for the employees of Lahti Mill

7 TEST RESULTS AND INSPECTION OF THEM

7.1 Overall equipment effectiveness in Lahti Mill

7.1.1 Availability

7.1.2 Performance

7.1.3 Quality

7.2 Material loss analysis in Bruchsal Mill

7.3 Survey for the employees of Lahti Mill

8 DEVELOPMENT SUGGESTIONS

8.1 Raw material

8.2 Employees’ attitude and knowledge

8.3 Maintenance

8.4 Continuous improvement

9 SUMMARY

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