CORROSION PREVENTION PROBLEMS IN THE SUPPLY CHAIN

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ABSTRACT

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Corrosion is a costly phenomenon, both financially and for people’s health, in the worst-case scenario. When a small, corroded structure collapses, it can cause a larger structure to collapse as well, leading to huge financial losses and potentially harming people at the same time. The practical section of this thesis is more about visual nuisances of corrosion that is not suitable for OEM parts, although it can lead to unwanted situations if ignored.

The thesis is done for Metso Minerals Oy in Tampere, for their Distribution Center Europe organization. The purpose of the thesis is to identify the problems in the supply chain that let the corroded spare parts reach customers, and to propose actions to prevent such from happening. The same proposals should also reduce the amount of corroded spare parts received, stored and sent from the DCE. The problems and proposed actions were identified from the data collected and analyzed from customer and warehouses claims, and from gathered statements from Metso’s experts.

Corrosion exists because the materials, in their elemental form, have tendency to return to their compound form, like they are found in the nature, by combining with other elements found in the environment by electrochemical reactions. The first section of this thesis about why and how corrosion happens, while the second thesis tells how to prevent corrosion through different means.

Keywords: corrosion, supply chain, surface finishing, protection
TIIVISTELMÄ

Tampereen Ammattikorkeakoulu
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Korroosio on kallis ilmiö, niin taloudellisesti, kuin ihmisten terveydelle pahimmassa tapauksessa. Pienempi, ruostunut rakene voi sortuessaan tuhota isomman rakenteen, mistä voi seurata suuria taloudellisia tappioita kuin myös mahdollisia henkilövahinkoja. Tämän lopputyön käytännön osuus keskitty kuitenkin enemmän korroosion visuaalisiiin haittoihin, mikä ei ole suotavaa OEM-osiille, mutta voivat myöhemmin johtaa myös epämukaviin tilanteisiin jos ne jätetään huomioimatta.


Korroosiota esiintyy, koska materiaaleilla on taipumusta palata alkuainemuodosta takaisin yhdisteeksi, niin kuin niitä esiintyy luonnossakin, yhdistymällä ympäristöstä löytyvien aineiden kanssa, sähkökemiellisten reaktioiden ajamana. Lopputyön ensimmäisessä osassa käsitellään miksi ja miten korroosiota esiintyy, kun toinen osa puolestaan kertoo erilaisista korroosionestomenetelmistä.

Avainsanat: korroosio, toimitusketju, pintakäsittely, suojaus
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1 INTRODUCTION

The subject for this thesis was suggested by Metso Minerals spare part specialist, wear parts claim handler and former DCE parts support team leader Anttiveikko Vierula from aggregate spare part team in Tampere, due to claims about corroded spare parts. The thesis was realized in Distribution Center Europe unit of Metso Minerals in Tampere. This thesis concerns spare part corrosion problems from DCE point of view along the supply chain, viewed through claims and expert comments. The purpose of this thesis was to suggest corrective actions to reduce the number of corroded parts the customers receive.

Before studying the material for this thesis, the author had little understanding about corrosion forms and mechanisms, as well as about all the steps that could be taken to prevent corrosion during the supply chain. Although there were some courses about materials in the university, the information was long forgotten. DCE quality processes were also quite unknown. A lot about material engineering, events in the supply chain and ERP and PDM systems was learned, in addition to corrosion and its prevention.
2 CORROSION

In this chapter corrosion and the mechanisms in its various forms are introduced, starting with the reason why corrosion exists and moving on to different types of corrosion and later presenting the effect of environmental factors. The focus is on metals, especially on steel and aluminum.

2.1.1 Defining corrosion

Corrosion as a phenomenon has been known to mankind before the start of times but the definition has varied over the years through increased knowledge about the subject. Ahmad Zaki from Institution of Chemical Engineers (2006) introduces six definitions from which some main themes are distinguishable: Corrosion gradually deteriorates and destroys material which is exposed to a reactive environment, causing chemical or electrochemical reactions on the exposed material and chemical or biochemical reagents. Corrosion is basically interactions between materials and surrounding environment. Ahmad (2006) also refers to corrosion as extractive metallurgy in reverse. (Ahmad 2006, 2.) Volkan Cicek (2014) adds material losing its properties to the definition (Cicek 2014, 15).

Metals, aside from noble metals, are found in nature in their low-energy state as various compounds, such as iron mineral hematite, which are much more stable than metals in their pure form, thermodynamically speaking. To make metal more useful to man the compounds – ores – are concentrated with high amounts of energy, heat, producing metals in their elemental form. The resulting high-energy pure metal is unstable in comparison and by natural tendencies it strives to revert to its low-energy state by releasing energy and combining with other elements in the environment, hence Ahmad’s (2006) definition about extractive metallurgy in reverse and the reason why metals corrode. (Cicek 2014, 19-20.)

For corrosion to occur, four basic requirements need to be present: An anode, a cathode, an electrolyte and a metallic path, together forming a corrosion cell. Anodes and cathodes are metal electrodes in the cell, the anode representing a negative and cathode a positive terminal. The more reactive and less noble metal acts as an anode that oxidizes, releasing electrons and positively charged ions which travel to the cathode where they are consumed, resulting in reduction of material. Electrons are transferred from anode to cathode.
through an electrically conductive solution called electrolyte, and current flows from cathode to anode through a metallic conductor, thus completing the circuit. (Ahmad 2006, 9). Reactions in the anode and the cathode happen at the same time and rate. Should they not, the circuit would not function. (Cicek 2014, 50).

It is worth mentioning that the anode and the cathode do not necessarily need to be two separate pieces of different materials such as copper and iron, but both can be in the same block of steel, for example. In this case two different points on the metal need to have potential difference for corrosion to occur. (Edu.fi & Kunnossapitoyhdistys ry.) Picture 1 depicts a metal bar in an electrolyte. Corroding anode has formed to the middle of the bar, generating ions and causing loss of metal. Non-corroding cathodes are on the sides.

![Components of corrosion](image)

**Picture 1. Components of corrosion** (Components of corrosion. King Fahd University of Petroleum and Minerals.)

### 2.1.2 Factors contributing to corrosion rate

Reduction rate is greater the further apart the anode and the cathode are in a galvanic series and the larger the cathode is compared to the anode in size. Metal impurity causes local electrochemical cells to form in metal, speeding up the corrosion rate in anodic metal. Metals, even pure ones, under unevenly distributed stress are easily corroded. Corrosion rate is greater if the corrosion product is soluble or volatile in the electrolyte, allowing the corrosion product to be washed away and exposing the anode to further reduc-
tion. Environmental factors contributing to the corrosion process are temperature, humidity levels, fluid dynamics, present impurities, oxygen and salt dissolved to liquid and pH, according to Cicek (2014, 51, 53-55.).

As temperature rises, chemical and electrochemical reactions increase, hence some corrosion types occur usually in high temperatures. Corrosion speed could even double if solution temperature rises 10-30 degrees Celsius and can start a corrosion process that can be maintained in a colder solution. Highly conducting electrolytes increase corrosion rate as corrosion current travels easier through the circuit. Oxidative solutions corrode metals more than reductive solutions and metal ions dissolved in acid solutions cannot form a protective reaction product layer, furthering corrosion. Corrosion rate is also dependent on the main components of the electrolyte and its redox potential, which means the potential of the solution to oxidize – the higher it is, the higher probability of corrosion when oxidizer in a solution triggers a cathodic reaction, which in turn causes anodic reaction. Corroding factors in solutions are usually dependent on each other. (Aromaa 2005, 17, 21-23).

2.1.3 Anodic reaction

An anode is less noble material of the anode-cathode pair meaning it has higher energy levels and greater oxidation potential. Metal ions are generated in the anode and some of them form with negative ions from the cathode on the metal surface as rust. Rust is formed because the ions do not dissolve in the electrolyte, so they separate from it (Ahmad 2006, 14). The anode also releases electrons which travel to the cathode through the electrolyte. The generated metal ions and released electrons are called oxidation which leads to corrosion and material loss. In addition to the beforementioned, the anode shifts to a higher valence state. (Ahmad 2006, 10-12; Cicek 2014, 53).

2.1.4 Cathodic reaction

The cathode is the more noble material of the two, and the primary reaction happening in the cathode is called reduction. The cathode consumes electrons the anode has released and decreases its valence state. (Ahmad 2006, 12). Acidity and alkalinity of the media can lead to various cathodic reactions such as hydrogen evolution or oxygen reduction. (Cicek 2014, 50).
2.2 Galvanic corrosion cell

A galvanic corrosion cell can be an anode or a cathode in a uniform electrolyte, or a metal with different conditions in the same electrolyte. For example, plates of iron and zinc submerged in a salt water solution is a galvanic corrosion cell where iron is a cathode which reduces, and zinc is an anode that oxidizes while salt water is the homogeneous electrolyte. (Ahmad 2006, 12). Two different metals, or same heterogenic metals, in contact to each other are also called a galvanic coupling, according to Philip A. Schweitzer (Schweitzer 2010, 9).

2.2.1 Oxygen concentration corrosion cell

An oxygen concentration cell is alike to a galvanic cell except that the anode and cathode of the same metal are in a heterogeneous electrolyte, such as a mixture of water and oil where different phases are distinguishable. As the solution is an uneven mixture of water and oil, chemical dissimilarity causes potential difference between regions on the metal creating an anode to a more chemically concentrated area and a cathode to a less concentrated one. (Ahmad 2006, 13).

Corrosion occurs because of differential aeration between anode, where oxygen diffuses less easily, and the cathode, where oxygen is more available. Typical concentration corrosion cells are pipes and tanks buried underground but can be present in a metal with spots of dirt on it. Even pure metals can be affected since different amounts of oxygen reach different areas of the metal. (Ahmad 2006, 13; Cicek 2014, 57) As the universe seeks to balance all things, the oxygen level lowers on the highest concentration area, causing that area to become cathodic in relation to the lower oxygen concentration area, making it anodic, creating a current flow (Schweitzer 2010, 11). Picture 2 depicts pipeline buried underground making the metal in less aerated clayey soil an anode, and metal in more aerated loam a cathode. Differences in oxygen levels are irrelevant for corrosion in atmospheric conditions but contributes a lot in underground applications (Ahomaa 2005, 17).
2.2.2 Electrolytic corrosion cell

An electrolytic corrosion cell can be characteristically alike to galvanic or concentration cell but with an external power source added to the mix. In this kind of a corrosion cell the anode is the positive terminal and the cathode negative, unlike in the previous corrosion cells, resulting in electrons travelling from anode to cathode through metallic path instead of electrolyte. (Ahmad 2006, 13).

2.2.3 Differential temperature cell

Differential temperature cell is formed when there is temperature difference between uniform metal pieces, or areas on a metal piece that are in homogenic electrolyte. The phenomenon is played out differently regarding the material of the electrodes and electrolyte composition, that dictates which electrode is the cathode and which is the anode. Differential temperature cell can happen in heat transfer equipment, to name one. (Schweitzer 2010, 10).

2.3 Forms of corrosion

While the beforementioned corrosion cells are the mechanisms of corrosion, this chapter introduces the forms in which the corrosion cells occur in practice. Pierre R. Roberge, a professor of chemical and materials engineering and an expert on corrosion, divides corrosion forms in three categories based on visual identification (2000):

- Group 1. Readily identifiable by ordinary visual examination
- Group 2. May require supplementary means of examination
- Group 3. Verification is usually required by microscopy (optical, electron microscopy, etc.)

(Roberge 2000, 333)

2.3.1 Uniform corrosion

Uniform corrosion, or general corrosion is the most common corrosion type. In this form of corrosion, the metal corrodes evenly on the exposed surface, usually due to chemical reactions or the metal dissolving into ions. The corroding substances on the environment breaks down the passive film on the metal and preventing it from forming again, exposing the metal to corrosion. Passivating film is discussed more in chapter 3. Uniform corrosion is easily measured and considered by designers, because the metal corrodes evenly along the surface. Granted, the environment of the application must be known. Uniform corrosion is usually measured in lost metal thickness over time, f. ex mil per year (mpy). (Schweitzer 2010, 27-31).

2.3.2 Intergranular corrosion

Due to heat treating a metal, grain boundaries are formed in the metal. The grain boundaries are small and may have different structure compared to the grain bodies, such as high amount of alloying metals on the grain boundary, leading to insufficient amount near them and lowering their corrosion resistance, or stainless steel missing corrosion-resistant elements on the grain boundary, and according to National Association of Corrosion Engineers (NACE), the impurities tend to be enriched at the grain boundaries (Intergranular Corrosion 2018). Because of the heterogeneity of the structure, the grain boundary or areas near it become anodic while the grain body becomes cathodic and since the anode is small, it corrodes quickly. (Schweitzer 2010, 32). In Picture 3 there are three distinctive corroded grain boundaries on an aluminum aircraft component. The corrosion usually travels along the lines at fast pace.

Intergranular corrosion in highly directional grain structures can lead to exfoliating. The corrosion product that requires about fivefold space compared to non-corroded metal, is stuck inside the metal, causing internal stress to the structure and splitting off the outer
layers of metal. This type of corrosion decreases load-carrying ability quickly and exposes non-protected metal surfaces for further corrosion. (Schweitzer 2010, 73-74).

![Picture 3. Corrosion on grain boundaries (Intergranular Corrosion. NACE)](image)

**2.3.3 Galvanic corrosion**

Galvanic corrosion, or dissimilar corrosion, happens when two metals are in contact with each other with an electrolyte present. Galvanic series will dictate which one will be the less noble metal, anode, and corrode. The anode corroding reduces chances that the cathode will corrode. Sometimes, the environment will play a role on the metal’s placement on the galvanic series. A passivating metal may be on the noble-end of the list in most scenarios, but in an unfavorable environment, the passive film may be swept away and prevented from forming again, making the metal active and dropping down on the list. (Schweitzer 2010, 36-37)

**2.3.4 Crevice corrosion**

Small spaces and gaps between a metal and another substance, be it metal or non-metal, causes crevice corrosion due to localized oxygen level differences. For example, washers on a base plate could potentially cause crevice corrosion. The size of the space or the gap usually invites liquid residence but does not allow its flow, making it stagnant. This type of corrosion is especially damaging to passivating metals that rely on the protective oxide layer but can occur in any metal and environments, and after the crevice corrosion is initiated, it progresses aggressively. (Schweitzer 2010, 38-40)
2.3.5 Pitting corrosion

Pitting corrosion starts with a broken protective film on the metal, followed by a tiny hole on the surface, increasing its depth rapidly. Pitting corrosion is hard to detect since the visible hole is small and can be hidden by the formed rust. Furthermore, the metal thickness stays about the same, as does the weight of the metal. This type of corrosion can easily render the victim structure useless due to full penetration of the structure, causing a water pipe leakage, for example, and can cause structural failure, in the forms of fatigue failure and corrosion cracking, to name a few. Pitting corrosion happens because of concentration cell corrosion, and requires the anode be small compared to the cathode, otherwise the corrosion is insignificant in most cases. The pits usually bore the metal in the direction of the gravity. The corrosion starts slow, and it takes some time for the corrosion to be visual. Once started, the phenomenon maintains itself without external help and continually increases the corrosion rate. (Schweitzer 2010, 41-42). Picture 4 depicts narrow, deep pitting corrosion. The brown-white area is the broken protective oxide film.

![Picture 4. Pitting corrosion (Pitting Corrosion. NACE)](image)

2.3.6 Erosion corrosion

When a material corrodes in an environment where it normally would not, because of mechanical force, such as a solution flowing on the material surface, the corrosion is called erosion corrosion (Aromaa 2005, 69). According to Aromaa (2005), erosion corrosion is a sum of mechanical corrosion caused by flowing solution and chemical or electrochemical corrosion (Aromaa 2005, 69). In a slow flow environment, the dissolved ions are washed off the surface, preventing formation of the passive film. Medium flow slows down the corrosion, while faster flow again increases the corrosion because the mechanical forces tear down the protective film. Usually erosion corrosion is seen as aligned pits or grooves on the surface. The solution can grow more acid in the pits, accelerating corrosion. (Aromaa 2005, 69-70). Among factors increasing corrosion rate are turbulence, gases or solid material in the solution, temperature, velocity, corrodent in direct contact...
with the metal surface or even bubbles, because of high pressure when they collapse near the material surface. Stainless steels are generally resistant to erosion corrosion while metals such as carbon steel and aluminum are prone to it. (Schweitzer 2010, 44-45).

### 2.3.7 Hydrogen damage

Hydrogen damage is caused by the hydrogen diffusing to the metal structure. Usually hydrogen diffuses to the metal during plating, such as electroplating but sometimes hydrogen is formed on metal surface as a product of corrosion, and is absorbed in. The hydrogen reduces the metal’s properties to be treated (Aromaa 2005, 83) and reduces its ductility and tensile strength (Schweitzer 2010, 58). When hydrogen moves to dislocations, preventing their movement, the metal cracks. The hydrogen also leads to internal fractures, stress corrosion and hydrogen blistering. Blistering is caused by hydrogen forming a molecule inside the metal structure, creating enough pressure to form a bubble inside. Again, enough bubbles cause cracking. Sometimes the hydrogen-induced fractures invite hydrogen bubbles that expands and joins the fractures together, furthering the deterioration. High-strength steels are especially vulnerable to this type of damage. (Aromaa 2005, 83-84). The risk of hydrogen embrittlement is present for example, in high-strength fixing items like bolts, in property classes 10.9 and above, among other applications (Würth 2016). During the electroplating of the bolt or during use, the metal surface experiences cathodic reduction, which forms hydrogen on the surface that diffuses to the structure (Schweitzer 2010, 58).

### 2.3.8 Other types of corrosion

In addition to the corrosion forms already reviewed, there are a few more that are briefly introduced. One of them is stress corrosion cracking, that happens, when a certain metal under tensile stress is in a certain environmental condition, temperature and pH levels. The conditions inducing stress corrosion cracking are material dependent, with each material having a specific nemesis-environment. The stress needed to invoke this type of corrosion can be even as small as 10% of material’s yield strength. Tensile stress can also lead to other forms of corrosion. (Schweitzer 2010, 46-49).

Biological corrosion looks like pitting corrosion but is caused by organisms. The organisms do not cause corrosion themselves, but rather expedite and enable it, meaning they
can be a part of many forms of corrosion. Some microorganisms speed up the corrosion while others modify the environment, for example to provide nutrients to the ones speeding up the corrosion so they can grow. The organisms can affect the corrosion rate in five ways: They can modify the environment to be corrosive or alter its composition, create electrolytic cells on the material surface or modify the surface film resistance, or influence the rate of the anodic or cathodic reactions. Microbes have an ability to degrade any naturally occurring compound. (Schweitzer 2010, 50-52).

When an element, usually the less noble, is leached from an alloy, the corrosion type is selective leaching. Again, the alloy and the environment dictate whether selective leaching occurs with that specific combination. Schweitzer identifies favorable conditions being high temperatures, stagnant solutions and porous inorganic scale formation. (Schweitzer 2010, 55-57). The phenomenon occurs, when the least noble metal dissolves faster than others, and can result in a structure full of holes (plug-type selective leaching) due to differences in nobility between phases (Aromaa 2005, 82). The other type of selective leaching is layer-type, where the less noble material dissolves evenly from the alloy (Schweitzer 2010, 56).

### 2.4 Atmospheric corrosion

Corrosion rate is mostly set by the time the surface of the metal is wet. The longer it is wet, the greater the corrosion rate. Materials have a material-dependent level of relative humidity after which the corrosion speed is greatly accelerated and below that level oxidizing ceases virtually completely. This level is also affected by corrosion products, such as chloride-rich rust on steel, and impurities found in the atmosphere that speed up the corrosion rate in lower relative humidity. Such impurities could be Sulphur, chlorine and nitric oxide for example. In marine environment chlorides are the biggest problem and in industrial areas Sulphur and its compounds. Visible dirt and particles can further the acidity of the electrolyte, and can either create oxygen concentration corrosion cell, due to potential differences, or galvanic concentration cell on the surface of the material. (Aromaa 2005, 24).

Ambient temperature affects corrosion rate, although it is quite insignificant compared to other contributing factors. In conditions under -20 degrees Celsius, corrosion stops virtually completely, and an increase of 10 degrees Celsius doubles the corrosion speed. Varying temperature can break protective layers on metals due to mechanical stress. Aromaa (2005) demonstrates the negligibility of temperature with comparison of corrosion rate in summer and winter and at night and during day; corrosion speed is higher in winter because of higher relative humidity and Sulphur levels, even though the weather is cold. Relative humidity is also behind greater corrosion rate during the night compared than during the day. (Aromaa 2005, 6).

Aromaa (2005) divides atmospheric corrosion behavior with formed protective layers in the following categories:

- Corrosion of chrome type metals (Aluminum, lead and alloys including chrome) ceases when the layer has been formed.
- Corrosion of copper type metals slows down with time as the protective layer grows with time.
- Corrosion of zinc type metals (zinc, magnesium and nickel) do not form the layer, and thus corrode with constant speed.

The type is dependent on environment as steel corrodes like copper in rural environment but like zinc in marine or industrial environment. Zinc, on the other hand, corrodes like copper in marine environment. (Aromaa 2005, 26).
3 CORROSION CONTROL

From corrosion cell perspective, there are four ways to slow down or repel corrosion, which are preventing the anodic or the cathodic reaction, removing the electrolyte, disconnecting the electric path (open circuit) and reversing the reaction direction on the anode, altering the corrosion cell’s effect (Aromaa 2005, 94).

In practice, there are six different methods to derail corrosion off the path of destruction, according to Aromaa (2005). The ways are as follows:

1. Meticulous design
2. Material choices
3. Coating
4. Altering the corrosion environment using corrosion inhibitors
5. Electric protection
6. Do nothing
(Aromaa 2005, 96)

3.1 Cathodic and anodic control

As a result of corrosion, metal’s surface is covered in rust (corrosion products deposited on the surface) and oxygen supply is reduced at the same time since oxygen has to diffuse through rust, slowing down corrosion rate. Reduced corrosion rate through reduction of oxygen is called cathodic protection, i.e., the metal is under cathodic control. (Cicek 2014, 52). The protective rust is a property of alloyed weathering steels, designed to prevent atmospheric corrosion (Schweitzer 2010, 31).

More aesthetic ways to protect metal from cathodic reactions would be painting, coating, inhibition and removing acidic components from solutions. Cathodic protection can also be used to reverse the corrosion cell’s process. (Aromaa 2005, 94). Painting and other coating protect the metal by either separating the metal from the environment, sacrificing itself or inhibiting (Aromaa 2005, 118). To achieve sufficient coating, the surface of the piece must be worked beforehand to be smooth and clean enough to allow uniform layer of coat. Rounding the edges of the piece is a good practice as it suits almost all coating. Without rounding the edges, the coat does not adhere to the surface, leaving the layer too thin. (Aromaa 2005, 100-101). Unalloyed or low alloy steels should be always coated as
they cannot withstand most environments without protection (Aromaa 2005, 106). Metallic coatings, such as hot-dip galvanizing, protects the metal by isolating it from the environment, and also by corroding itself, the latter only when the coat is less noble material than the protected material. Common metal coating is zinc, and with hot-dip galvanizing, steel is over tenfold more resistant to corrosion than unprotected steel in atmospheric conditions. (Aromaa 2005, 26, 121). Inhibitors are agents that react with the environment and protect metals from corrosion through various means, such as by creating protective layer on the metal surface, by passivating the metal or by neutralizing acidic components on the electrolyte. Common inhibitor is so called VCI, volatile corrosion inhibitor, that forms a protective layer on the metal. (Aromaa 2005, 123-124).

Sometimes corrosion products form a continuous thin protective layer of oxide on the metal surface which prevents ions traveling from metal-oxide interface to oxide-liquid interface making the metal noble. Metals forming a film of oxide, such as aluminum and stainless steel, are called passivated metals and they are said to be under anodic control. It is worth noting that the quality of the formed oxide film is metal-dependent. Metals such as magnesium and calcium generate a porous oxide layer through which oxygen can diffuse, and continue corroding the metal, easier than through aluminum oxide film, for example. In high temperatures, passive metal may become active. Corrosive anions in electrolyte can destroy the layer, causing pitting corrosion, and prevent it from forming again, greatly furthering corrosion. (Cicek 2014, 52, 54-59). Passive film may break down in high potentials, called transpassive region, allowing corrosion rate to grow. Passive film does not stop the corrosion altogether but slows it down significantly. (Ahmad 2006, 97, 102). Protective film can be achieved by mixing favorable components to the solution, passivating metal (Aromaa 2005, 94).

### 3.2 Removing the electrolyte

When possible, designing the structure so the electrolyte cannot rest on or be stored on metal will reduce corrosion. Though simple to say, always designing such structures in practice is quite a feat. Pockets and gaps on the design invite liquid into them, concentrating the still solution over time and speeding up corrosion rate, and the liquids might prove to be tricky to remove from the structures. Aromaa (2005) regards the gaps to be the weakest point in structures. During transportation it is preferable to dry the air inside the package, removing the electrolyte. (Aromaa 2005, 94; 96-97).
3.3 Electric path

When the anode and the cathode are electrically far away from each other, the electric path is disconnected since resistance grows (up to infinite) as per Ohm’s law and the circuit is not closed anymore. In joints with screws and bolts this can be achieved by using bushings and washers. Also isolating seals and gaskets can be used in between the parts. (Aromaa 2005; 94, 99-100).

Cutting the electric path could be considered to prevent galvanic corrosion in applications that have different metals fixed on each other causing potential difference. Galvanic corrosion can be diminished in engineering stage with the right material choices. (Aromaa 2005, 96,98).

3.4 Material choices

Determining the correct material and alloy for the correct environment for an application is vital. Electrochemically, corrosion resistance comes down to two things: Material nobility and capability to form protective layers on the material surface. Using alloys helps battle corrosion, but to be able to choose correctly, the application environment must be known. Certain environments are unfavorable to certain metals and alloys, allowing a corrosion reaction by activating the metal, either by removing the protective layer or preventing it from ever forming. (Aromaa 2005, 94-95).

If it is not possible to use metals noble enough or protect the metal well enough, the structure can be designed to have a corrosion allowance, which takes the predicted corrosion rate into account. For example, if a steel structure needs to last for 5 years, and the calculated corrosion rate on C3 atmosphere (urban or industrial area with moderate Sulphur dioxide levels or coastal area with small amounts of salt), according to ISO 9223, is 40 mpy, the structure would need to be 200 mm thicker due to the corrosion. (Schweitzer 2010, 31; Aromaa 2005, 25-26).

When designing a structure, it is important to use same the material throughout the whole structure, or at least materials close to each other in galvanic series, in other words, about equally noble metals. This way galvanic corrosion potential is reduced. (Aromaa 2005, 97-98)
3.4.1 Alloying additions

Adding more passivating alloying metals to a less passivating base metal reduces the rate of corrosion. For example, adding the alloying metal chromium to the base metal iron induces passivity because of the forming protective film (Ahmad 2006, 102), therefore high alloy steels are more suitable to be used against corrosion than unalloyed or low alloy steels (Aromaa 2005, 106). Stainless steels have under 1.2 % of carbon, and consist of at least 10.5 % chromium, which is the main alloy and defines the corrosion resistance on ferritic stainless steels. Martensitic stainless steels have high carbon content and around 13-17 % of chromium. Molybdenum and nickel can be added to improve corrosion resistance. The main alloys on austenitic stainless steels are chromium and nickel and other usable alloys are copper, titanium, niobium and nitrogen. Alloy content on austenitic stainless steels can be well over 50 %. (Aromaa 2005, 106-108).

In some conditions, adding noble metal to a base metal increases corrosion rate rather than decreases it. For example, adding platinum to chromium in highly oxidizing acid environment causes a potential rise up to transpassive region. (Ahmad 2006, 103-104)
4 METSO MINERALS AND DCE

4.1 The company

Metso was established in 1999 when machine and metal industry company Rauma and paper and board machines manufacturer Valmet merged. At this time, Metso was involved in paper and pulp, construction and civil engineering and process and energy industries. In the 2000’s Metso acquired various paper machine related businesses and technologies as well as crushing and mining processing, valve and automation solutions and manufacturers. Later on, Metso focused more on aggregate and minerals and flow control businesses. (Our history 2018).

In the early 2000’s Metso focused on making a better structure for the concern and improving viability by selling business lines not deemed Metso’s core business functions. Metso’s divestments included sales of forest machines, some process industry automation and hunting and sports rifle business. Later also paving and compaction, drilling, drives and hydraulics business lines were sold. (Metso yrityksenä. Historia 2018).

In 2013 Metso was demerged into Metso and Valmet with Metso handling mining and aggregates, flow control and oil and gas industries while Valmet took on pulp, paper and power businesses. Shortly after, process automation systems were sold to Valmet and Valmet Automotive also divested while focus shifted more and more towards services business. (Metso yrityksenä. Historia 2018).

In 2018 Metso had 12000 employees in over 50 countries and 80 service centers, spanning six continents (Metso yrityksenä 2018). Metso’s turnover was 2,7 billion euros in 2017 (Metso sijoituskohdeena 2018).

Metso’s strategy is built around five factors: Customer-centricity, services locally and throughout life cycle, innovation, operational excellence and skilled and motivated personnel and leaders. Among Metso’s vision can be found themes such as sustainability through renewable energy and reduced energy consumption and health, safety and environment. (Strategy and vision 2018).
4.1.1 Metso Minerals

Groundwork for Metso’s Minerals (Aggregates and Mining) business was laid in 1970’s when Lokomo Oy was sold to Rauma-Repola, acquiring line-produced crushers. Later, Rauma-Repola bought Nordberg, which produced crushing equipment. With this move Rauma-Repola gained various gyratory and cone crusher families as well as locations in the US and South Africa. Shortly after, Rauma-Repola acquired Bergeaud in Macon. Over the years Rauma-Repola expanded their crushing product range and locations globally with purchases such as mobile screens manufacturer Masterskreen in Ireland and vertical shaft impactor Barmac in New Zealand. After Metso was born they acquired Swedish rock and minerals processing solutions company Svedala Industri. (Our history 2018). Metso’s latest acquisition in minerals business is Swedish mobile crushing and screening solution provider P.J. Jonsson och Söner (Metso closes its acquisition of P.J. Jonsson och Söner in Sweden 2018).

Metso Minerals product range includes stationary grinding roll, jaw, gyratory, impact and cone crushers, such as vertical shaft impactor crusher Barmac, C series jaw crusher and HP series cone crusher. C series jaws are often used in the primary crushing stage and impact crushers in the last stages of crushing. Crushers are fed material with a feeder, such as VF series grizzly feeder or PF pan feeder. Feeders remove undersize material from the process before the crusher to improve throughput and wear part lifetime. In the primary crushing stage, oversize rock can be dealt with MB series rock breaker. Conveyors move the material from the feeder or crusher to the product pile, screen or next stage of crushing. Screens, such as CVB inclined screen, separate different sized material into conveyors either to be moved into product piles, ready to be transported, or to further reducing and shaping of the material. Beforementioned products can be fitted into a mobile solution such as Lokotrack (from now on LT) or Nordwheeler (NW). One LT or NW can handle one crushing stage and is equipped with feeder, crusher, at least one conveyor and optional screen along with other additional equipment. Metso Screentrack (ST) is equipped with a screen and multiple conveyors. (Aggregates. Products 2018).
4.2 Distribution Center Europe

Metso has various distribution centers (from now on DC) around the globe, such as DC Europe (DCE) with a small warehouse and office in Tampere, Finland and main warehouse (outsourced to CEVA Logistics) located in the Netherlands. Other notable DCs include DC Columbia in the United States, DC Macon in France and DC South Africa.

DC Europe supports selected service centers (supportive service office, SSO) and distributors, with wear and spare parts, globally. Generally, DCE’s product range is basically all equipment that are or could be mounted in mobile solutions. This includes products introduced in chapter 4.1.1. Complete machines are out of DCE’s scope as they are handled by capital equipment unit.

DCE consists of smaller units; procurement, sales, logistics and warehouse operations. Procurement makes sure items deemed worthy of stocking are always available by overseeing local item traffic, submitting purchase orders (from now on, PO) to Metso’s suppliers and expediting orders on the sales unit’s request. Customer service representatives (CSR) in the sales unit handle order-related matters, such as expediting existing orders and sales order confirmation. Parts support in the sales unit is responsible for quotations, improving lead times, offering alternative solutions and solving various problems that prevent the customer from ordering the wanted item. The logistics team books inbound and outbound transports for goods, handles customs clearance and otherwise ensures the deliveries are running smoothly, on time. Communication between warehouses and DCE is orchestrated by warehouse operations, in forms of operations improvement, problem solving, warehouse and customer claim handling and quality. Members in the team are often involved in ongoing projects to improve customer satisfaction throughout the supply chain.
5 PROBLEMS AND CLAIMS ANALYSIS

In this chapter, DCE quality functions and supply chain are explained and various problems regarding DCE supply chain are introduced. Problems have been identified using claims and statements from Metso’s experts. Claims are reviewed, and the gathered data analyzed. Although this thesis concerns spare part sales, capital equipment is frequently mentioned and compared to.

5.1 DCE and quality

5.1.1 Abnormal quality

Sometimes items not fulfilling customer expectations or Metso’s quality standards move in the supply chain, such as corroded parts. There are many possible reasons for the anomaly and all DCE units can be involved when a quality defect is detected. First, the part is received in the warehouse’s inbound where goods are checked. Upon evaluating the part to be subpar, or rusty in this context, they will submit a claim to warehouse operations and procurement. The former handles the claim and their quality engineer tries to find out why the part is rusty by going through drawings and Metso’s quality requirement documents, while the latter claims the vendor for the part if needed. In another stage, the corrosion can be detected in outbound before dispatching the goods, due to prolonged storage, for example. Again, they will contact warehouse operations and this time the responsible CSR to alert the customer if the delivery will be delayed as a result. In urgent cases the CSR can contact parts support or quality engineer to determine if the part could be used despite the corrosion or to find alternative solutions. In an unfortunate event of a customer receiving a dissatisfactory part, they will contact the CSR and logistics responsible who will make sure a replacement is sent out and reaching the customer as quickly as possible. The customer will also claim the costs through Metso’s claim systems.

5.1.2 Claims

As a part of the thesis I analyzed corrosion problems through quality claims made by customers, warehouse and procurement. Customers claim subpar parts through Lotus Notes’ quality claims which are handled by Metso’s quality engineers and warranty personnel. Intercompany (SSO) and supplier claims are made in SAP software by and for
procurement agents. Intercompany claims are also made in Customer Feedback, a DCE Sharepoint site. CEVA has their own database where they submit and receive outbound, inbound and customer claims. In the beforementioned systems, multiple claims about the same case can be made and addressed to different parties.

Quality engineers try to pinpoint and fix the root causes for bad quality parts in the supply chain to prevent problems in the future. In their objective, they are involved with various parties, such as procurement, specialists, warehouse, vendors and designers to promote superb quality.

5.1.3 Supply chain

Metso Minerals is mostly a contracting company that has suppliers all over the world. Most items are Metso’s own design, and some are commercial components. As modern crushing plants require high-quality materials and finishing, precise control systems gathering lots of data using sensors, conveyors, tramp material detection and segregation and different kinds of power sources, crushing plants are not just mere chunks of steel put together. Since a plant requires a variety of parts to work smoothly, the company requires a variety of contractors to achieve superior quality and fulfill material needs. Some highly engineered Metso design items are exceptions to sourcing as they are made in Metso’s own factories.

A Metso design item indicates which Metso engineering faculty has designed the item. As the item is expected to be mainly used in that local factory (for assembling new machines), the item is then sourced from a local or close-by supplier. Other Metso locations then source the part from that factory location. For example, historically LT parts are usually Tampere design, therefore selected suppliers are relatively close to Tampere and Metso sales organizations purchase LT parts from DCE. The designing unit states the item requirements in the drawings or general documents, such as general surface finishing documents.

The purchaser can override requirements by stating new requirements in the PO sent to a vendor, as the PO is considered the highest requirement. The order is

1. Purchase order
2. Drawing

After the PO is sent and supplier has manufactured the part, it must be transferred to Metso’s warehouse (or sometimes, straight to customer). Metso’s dedicated global packing team and global procurement have created requirements for supplier packing, taking a stand i.a. in type of crates and pallets and their stackability, product protection and corrosion prevention during transport and storage and different type of freights (sea, air and truck).

Upon receival of vendor delivery, warehouse personnel check the contents and quality and check the parts in to stock. Parts will be stored for an indefinite length of time, although mostly parts in the warehouse are either for confirmed customer orders, or another usual reason is a foreseen demand for the part, making the part storage worthwhile, as deemed by product liner experts or software monitoring item traffic, to increase availability.

Once the customer has ordered a part, the warehouse picks and packs it. Warehouses have their own packing requirements and methods created by global packing and warehouse operations teams. The packing requirements involve special requirements for hazardous materials and corrosion prevention, transportation type, dimensions, and sometimes, destination country requirements. The package is then dispatched using selected freight mode and forwarder.

Metso location, distributor or end customer will then receive the part. Metso location will have about the same regulations as the sending location. Distributor storage is handled in their own methods. Distributors are expected to stock at least critical spares and service parts for machines in their scope and area. Standard Metso warranty for the part is six months after it is received, or 12 months with prolonged storage in receiver warehouse.

5.2 Problems

5.2.1 Designing and surface treatment documents

Designers have created part requirements and surface finishing documents mostly with production in mind. Older Tampere design items had no indication of surface treatment requirements in drawings unless they were different from general surface treatment instructions. In later drawings, there is reference to a surface treatment document that is to
be followed. The designing unit seldom updates drawings for items that production does not use anymore, so older drawings do not have any reference to said documents.

With document references for parts in various information systems and drawings, document control and updating becomes an issue. When a new surface treatment document is approved for use, it is difficult to update all old references and link to the new in systems such as SAP, Aton and Teamcenter. Items designing creates, have relations to the documents. When a new document is approved, the old one is replaced by the new in Metso’s systems. However, the replacements might not be clear to the suppliers as the replacements are not clearly stated in the documents themselves. Different Metso factories use and have used their own surface treatment instructions for suppliers, requiring manufacturers to refer to multiple documents across their offering.

Tampere factory usually orders the needed parts in large assemblies, whereas DCE purchases in smaller parts, because in an assembly there is usually one or two small parts the customer needs. The assembly drawing might require specific surface finishing and expects the subparts to be treated the same way, leading to no surface finishing instructions in subpart drawings. This could be especially true to galvanized assemblies, as galvanized is only done when the drawing dictates so. Different surface finishing might lead to a galvanic pair, corroding the anodic part. Sometimes Tampere factory also orders parts that do not have surface finishing at all, because they will do it themselves, for example, paint the assembly once it is in painting order. When DCE orders the same part, it might be inadequately protected.

Factories use and order parts for planned and forecast unit construction, meaning part throughput is relatively quick. On top of that, many parts are hidden from sight inside the machines, making little corrosion no problem in irrelevant places, such as non-machined surfaces that usually corrode uniformly. DCE also orders parts against customer orders and forecast but sales are more unpredictable and in a worst-case scenario, stocking time can be prolonged first in DCE warehouse, then in SSO and finally in distributor warehouse before reaching the customer. DCE sells separate parts as small as screws and nuts, making corrosion stick out in any item.
Metso’s latest surface treatment instruction document N11529634 “Painting system D1 for steel and iron surfaces” specify a general method of protection if nothing else is specified – a certain painting system. Galvanizing is done only when specified in the drawing, except for loose fit sliding surfaces, that are instructed to be electroplated in surface treatment instructions. The loose fit sliding surfaces should have enough room to work, after the protective layer is formed on the surface in the electroplating process. The instructions list component categories for items that are not to be painted but protected otherwise using certain protection agents and methods, such as protection waxes and sprays or the before-mentioned electroplating. However, the list does not cover all products that might be more sensible to protect rather than paint. An example could be items made from bulk materials, such as washers or bushings made from bulk bar that has the same diameter, as drawings require the washers or bushings to be, before any processing. Another problematic material could be sheet metal. The table for protection agents and methods lists “Ready-made purchased components with insufficient or without any surface finishing”, which could be interpreted as bulk materials, this kind of protection is not allowed per the before-mentioned rules that lists to-be-protected items.

The N11529634 states precision surfaces are not to be painted but to be protected against corrosion, because the tolerance and surface roughness does not allow painting. This should basically cover a wide range of machined surfaces. However, non-machined surfaces are not discussed in similar way, leading to ambiguous corrosion protection rules regarding non-machined surfaces. The surface treatment documents refer to Metso instruction for packing of products, regarding of protection during transport.

Document N11530835, “Galvanizing of steel and iron structures” suggests supplier to protect fasteners and other structural connections the same way the structure is protected, to eliminate galvanic couplings. For example, in galvanized structures the bolts and nuts should also be galvanized. This way, less instructions for protection in the drawings might be needed for large assemblies that factory purchases from supplier but does not work in spare part business with separate single small components.

Some example cases include Macon designing unit’s surface finishing instructions. All Macon drawings have referrals to the used documents and an indication of surface cleaning and finishing level. The said case indicated that all suppliers do not have the surface
finishing documents, as procurement had to send one supplier the documents after warehouse claimed rusty parts from the supplier in question. Macon has had three different surface finishing documents, and an appendix, of one of these documents, that is referred in many drawings. The oldest document, 03-03-01, is from (possibly before) the 90s. A Macon designer confirmed it has been replaced by document N11510379, which in turn has been replaced by N11529634. 03-03-01 is not found in Aton. N11510379 can be found there, but it has not been marked as replaced. The current “harmonized” document N11529634 has a table comparing the latest document’s surface finishing levels to Tampere and Macon documents. Again, there is no clear indication the old documents are replaced.

5.2.2 Sourcing and supplier

Generally, DCE sources metal parts from suppliers defined by factory sourcing unit. Tampere production has their own procurement and quality teams who are tasked with making sure suppliers’ instructions are up-to-date, but there are vendors who are of little significance to production, and vendors from whom the factory has ceased acquisition. DCE has almost 400 suppliers from which over 150 are defined vendor only for DCE, not for the Tampere factory (Macon suppliers are not counted in defined vendors). This means there is a flaw in document distribution and a possibility of supplier not having up-to-date documents, or in the worst-case scenario, not having the documents at all.

As mentioned in previous chapter, some old parts do not have surface treatment requirements in drawings and suppliers are expected to use general instructions in these cases. However, some items have surface treatment document relation in SAP, and when submitting a PO to supplier via SAP, it prints the document code on the PO (for a single item, not for the whole PO). This leads to some items having document requirement in the PO and some not, even when all items should be protected according to the general instructions, at the very least. At the end of the PO, it is states that surface finishing is to be done according to instructions. All in all, the current POs can be unclear and give mixed instructions to the supplier. Picture 5 shows how the first item, brush, has only drawing linked to it, while the second item return rod has other documents, among them the surface finishing document N11447786.
Requirements in drawings are another problem when the document the drawing refers to is not valid anymore. As stated before, requirements in POs are given highest priority, then drawings and the general documents have the least priority. When a surface treatment document is replaced, the new document must state clearly which old documents it replaces, otherwise the drawing’s requirements are given higher priority.

In a certain case of Metso trying to claim supplier on washers that were all uniformly corroded on non-machined surfaces, the supplier stated that there is no surface requirement in the drawing. This indicates the supplier are not utilizing the general surface treatment documents and it is up to the supplier to decide if they want to deliver a corroded part or not. Inadequate protection against corrosion becomes even bigger problem, if the parts are already corroded, or will soon corrode after arriving to Metso’s warehouse, because Metso’s general spare part warranty is six months (can be up to 12 months in prolonged periods of storage). The early-stage corrosion leads to further problems due to current warehouse instructions.
5.2.3 Packaging

Upon consulting procurement and packaging experts, I was given four different instructions for packaging. There were instructions for suppliers from procurement team, different instructions for suppliers from packaging team, and then spare part instructions for Born and general “rule of thumb” instructions when to apply VCI.

“Supplier Packing Instruction”, received from the procurement team had little information about corrosion protection. It urges suppliers to protect machined and unpainted surfaces properly with grease or VCI plastic. Later, when listing special requirements for freight modes, the VCI plastic and grease is advised to be used only with ocean freight.

Supplier instructions from the packaging team, “Metso Inbound Packaging Requirements” states that materials subject to corrosion shall be protected with VCI, oil or other required means. There is also rule-of-thumb advice on VCI, giving directions when to use VCI. For example, corroded, cast or standard painted materials are not protected but parts for long term inventory, oiled parts and electrostatic painting and porous surface is to be protected. General guidelines regarding when to use corrosion protection on which transport type and on which packaging type. To mention a few, heavy duty pallets transported via air or courier are to be wrapped in VCI plastic, but carton boxes and plywood cases do not need the plastic. Road transport in pallets require oiling and the VCI plastic wrapping. There is also a special requirement for South America, China, India and South Africa. All surfaces sensitive to corrosion need to be oiled and wrapped with the VCI plastic in all transport modes and packages. Just like in surface treatment documents, this document tells that additional packaging requirements can be written on a PO.

Instructions made for Born warehouse, “Rules of thumb for: - Selecting Optimal packing -Packing material/shipment”, tells to protect corrosion-sensitive materials with VCI and to protect against environmental influence. Packing process guidelines repeat the same. The instructions also have guide for selecting the best container for a freight mode, but unlike “Metso Inbound Packaging Requirements”, there is no mention about corrosion protection.

Lastly, “VCI Application: Rules of Thumb” tells more about ideal conditions when to pack effectively, corrosion-wise. Cold parts are not to be packed in warm atmosphere and
hot parts not to be packed in cold atmosphere and gloves are required when handling metallic parts because perspiration corrodes metal. Spare part in direct contact to wood, paper or cardboard is to be avoided, due to their possible corroding acid base. Also, the wooden box material is controlled because of biological corrosion that might happen with wrong type of material. The instructions also include the same directions when to use VCI, but it contains less requirements. Cast and standard painted parts are not mentioned in these instructions.

The beforementioned instructions are a bit conflicting and confusing when different instruction documents about the same topic are given to a supplier. There might be some miscommunication, both internal and regarding the information conveyed to suppliers. Another problem can be that suppliers might protect multiple parts in a single container with VCI, which is taken off in our warehouse and not reapplying it for stocking or for deliveries. Sometimes DCE separately requests supplier to do single packing so that all parts get their own VCI protection.

5.2.4 Warehouse

Quality supervising is inadequate in the warehouse. Corroded parts are often overlooked because there is no good definition when a part is too corroded for sales. Currently it is largely up to warehouse personnel to make the decision. Unclear definition leads to warehouse stocking parts that are rusty on arrival, and rusty parts delivered to customer, when, ideally, they should be reported to Metso and then costs claimed from supplier. There was plans to do proactive checkups for the inventory, but it was halted because of the beforementioned, unclear definition to recognize parts that are too rusty.

Another problem could be that the use of VCI, as per packing instructions, is sometimes ignored due to hindered packing performance. In a busy warehouse environment with lots of pressure to send out parts in time, VCI plastic could be seen as a nuisance that takes too much time to wrap around the items.

5.2.5 Returned parts

There is no referral on how to protect parts that will be returned. Customers, distributors and maybe even SSOs, to some extent, can return the parts with inadequate protection,
since the original protection agents might have been worn off. There was a case when an
adjustment ring was returned from Portugal, all rusty. When inspected further, the ring
had been in DCE warehouse for a couple of years and before that, it was already returned
from South Africa, while the surfaces were probably never re-protected with protective
agents it might have needed. The part had been in warehouses and in transport for at least
six years, before that, there is no log when the part was originally received from supplier.
This indicates there is no proper quality control in warehouses, and not enough stress on
re-protecting items, when they are sent back, and when sitting in inventories for a long
time. This is true to stock allocation as well.

5.3 Claims analysis

Claims were collected from claims databases: CFCs in Lotus Notes, SAP claims using
transaction QM11, Customer feedback in Metso Sharepoint and ODRs (Order discrep-
ancy report) in CEVA Sharepoint. Relevant claims were filtered from the mass using
keywords “rust”, “corro” and “oxid” as there was no better way to find claims only about
corroded parts. It is worth noting that not all claims were accepted by warranty handlers,
by the time they were gathered. In total, 48 claims were examined from period of 16
months (from start of January 2017 until May 2018).

The following data was collected from the claims: Customer country, date, sales or de-

divery number and part number. Using the sales or delivery number with the part number,
it was possible to track the delivery, since part’s batch number is recorded on the docu-
ments. Using the batch number, the supply chain can be observed from the moment of
receival in one of Metso locations, up to dispatch to a customer from our warehouse, with
delivery type information. It also enables vendor data and relevant dates to be seen. Part
number information leads us on to document relations in SAP, if the part has them set up,
and on to the drawings in Aton, where linked surface finishing document can be checked,
along with the designing location information.

Table 1 below shows how many Metso design or commercial items were in the claims.
TD stands for Tampere design, items that were designed in Tampere. MD is for Macon
design for items engineered in Macon. C means commercial items and D (C) items that
were marked as design item but clearly were commercial items. The results tell that the
corrosion problem is mostly present in Metso design items, equally in both Tampere and
Macon locations. Although greatly more design items were corroded as per the sampling, the design-to-commercial-item ratio of all items in the database must be high too.

Table 1. Metso design or commercial item

<table>
<thead>
<tr>
<th>Design / commercial</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>TD</td>
<td>20</td>
</tr>
<tr>
<td>MD</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>4</td>
</tr>
<tr>
<td>D (C)</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>48</strong></td>
</tr>
</tbody>
</table>

Table 2 presents how many claimed items had which surface finishing document. Almost half of the claims were about items without any surface treatment document references in the drawings, which is indicated with “No”. About one fifth of the claims were about document 03-01-01, which is an old document used in Macon and Metso USA drawings. Possibly dating back to the 80s, it has been updated until early 2010s, when it’s successor N11510379 were introduced. N11510379 was featured in 7 out of 48 claims. A bit over 10 percent of the claimed items had referrals to document 70 50-500101F0, which turned out to be an appendix to 03-01-01 from the 90s, meaning it lists the same requirement as 03-01-01. N11447786, a Tampere document, was involved in five claims. Last document, N11529634 which had one claim, is the latest document, and it was created to replace both Tampere’s N11447786 and Macon’s N11510379. The results indicate that most Tampere-design items claimed were without surface treatment document reference in the drawings, and Macon-design items had some sort of document linked to them. This reveals different way of thinking between Tampere and Macon. As older Tampere drawings had no indication of used document, it meant that (the latest) general document was to be used. In Macon, they have diligently written the document number and a mention of used surface treatment system to every single drawing. Macon has not always been a Metso location, but acquired late 20th century, explaining the difference in reasoning. The information about the documents was taken under microscope to see how different documents (or no document at all) fared against each other.
Table 2. Number of claims for each surface finishing document

<table>
<thead>
<tr>
<th>SF Document</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>20</td>
</tr>
<tr>
<td>03-01-01</td>
<td>9</td>
</tr>
<tr>
<td>N11510379</td>
<td>7</td>
</tr>
<tr>
<td>70 50-500101F0</td>
<td>6</td>
</tr>
<tr>
<td>N11447786</td>
<td>5</td>
</tr>
<tr>
<td>N11529634</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>48</strong></td>
</tr>
</tbody>
</table>

Table 3 indicates, how many of the claimed items originated from vendors, that Tampere factory uses. Over two thirds of the items were from approved vendors for the factory, as “Yes” indicates, while the rest were not (No). Although the remaining one thirds are not in use by Tampere factory, it does not mean Macon factory do not use them. This data was tracked, because there was a doubt, that suppliers not used by Tampere factory, have not received the related surface treatment documents.

Table 3. Claimed items that were from Tampere factory suppliers

<table>
<thead>
<tr>
<th>Prod supplier</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>13</td>
</tr>
<tr>
<td>Yes</td>
<td>34</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>47</strong></td>
</tr>
</tbody>
</table>

Table 4 is about the cost of the claimed parts. The items have been divided into categories, depending how much they cost, with steps of hundred euros. About half of the items cost under 100 €. 20 % of the items cost between 100-300 € and the number of items valued between 300-1000 € were 11, or about 23 %. The four parts left cost over a thousand euros, to about 15000 €. The table tells that the corrosion problem is the most prevalent in cheap items, that are more likely to be produced and sold in larger volumes. It might indicate suppliers having more stress on the more expensive parts, to keep them rust-free longer. Also, the more expensive items tend to have some extra instructions on the finishing than the cheap ones. It is also possible that the small, cheap items are packed and stored, touching each other, with less protection, allowing the corrosion process to accelerate. The fact that cheap items are manufactured and sold more, resulting in more claims, downplays the comparison of the results.
Table 4. Cost of claimed items

<table>
<thead>
<tr>
<th>Part cost / €</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>23</td>
</tr>
<tr>
<td>100-200</td>
<td>7</td>
</tr>
<tr>
<td>200-300</td>
<td>3</td>
</tr>
<tr>
<td>300-400</td>
<td>4</td>
</tr>
<tr>
<td>400-500</td>
<td>1</td>
</tr>
<tr>
<td>500-600</td>
<td>2</td>
</tr>
<tr>
<td>700-800</td>
<td>1</td>
</tr>
<tr>
<td>800-900</td>
<td>1</td>
</tr>
<tr>
<td>900-1000</td>
<td>2</td>
</tr>
<tr>
<td>1500-1600</td>
<td>1</td>
</tr>
<tr>
<td>2800-2900</td>
<td>1</td>
</tr>
<tr>
<td>6600-6700</td>
<td>1</td>
</tr>
<tr>
<td>15000-15100</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>48</strong></td>
</tr>
</tbody>
</table>

Table 5 shows the freight mode a claimed item was delivered either to customer or to Metso warehouse. The incoterms indicate, to which point Metso is responsible for the cargo, usually to a seaport or to an airport. After that point, the customer takes over, meaning the cargo had an unknown follow-up carriage method. Almost half, 22 out of 48, claims were air deliveries. Trailing just behind were truck deliveries with 18 claims and lastly, ocean deliveries with 8 claims. The result is surprising as I assumed deliveries via ocean, via salty environment, would dominate the category. The results would indicate that either air and truck deliveries are improperly packed compared to ocean deliveries, or the delivered items were corroded to begin with. However, the data does not tell the total percentage of each freight mode of all deliveries Metso makes. Ocean freight could be less used compared to truck or air.

Table 5. Freight mode

<table>
<thead>
<tr>
<th>Delivery type</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>22</td>
</tr>
<tr>
<td>Truck</td>
<td>18</td>
</tr>
<tr>
<td>Ocean</td>
<td>8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>48</strong></td>
</tr>
</tbody>
</table>
Table 6 depicts the time it took the claimed goods to arrive from warehouse to customer. This data is not tracked by Metso but could be deduced by the time it left Metso warehouse, to the time the claim was made, meaning the real delivery time could have been a little shorter than the time in the Table 6. The table also includes the time the goods were in customs, for example. About half of the claimed items were delivered in less than ten days. Out of these, two were truck deliveries to nearby locations and the rest were air freight. Six claims were delivered in ten to nineteen days, three via air and three via truck. The first ocean delivery arrived to customer in 30-39 days and deliveries that took 60-79 days were all via ocean. The collected data hints that most items could have been rusty before dispatching them, since most shipment times were relatively short. It was not possible to deduce shipment times of all claims, hence only 34 claims were examined.

Table 6. Delivery time in days, from warehouse to customer

<table>
<thead>
<tr>
<th>Delivery days</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-9</td>
<td>15</td>
</tr>
<tr>
<td>10-19</td>
<td>6</td>
</tr>
<tr>
<td>20-29</td>
<td>3</td>
</tr>
<tr>
<td>30-39</td>
<td>2</td>
</tr>
<tr>
<td>40-49</td>
<td>1</td>
</tr>
<tr>
<td>60-69</td>
<td>6</td>
</tr>
<tr>
<td>70-79</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>34</strong></td>
</tr>
</tbody>
</table>

Basically, Table 7 tells the time frame, when the item was first received by Metso to the time it was sent to the customer that made the claim. In most cases, the table tells how long an item was in a warehouse before dispatching. There were also some instances, when an item was returned from a customer, or from another Metso location, before sent to the customer that made the claim, so they include freight times as well and storage time in another location. Over half of the items were under 90 days in Metso possession before dispatching. About fourth of the items were over 90 days and under 180 days at Metso’s. 180 days, or six months, is also the warranty Metso gives to its products. The remaining ten items were in Metso’s custody from 180 to 630 days, except for one item that had travelled in various Metso location for about 2200 days. The results indicate that claimed items have not been up to Metso’s warranty time, as further cemented by Table 8 that breaks down the delivery-time table (bolded numbers) to warehouse times (non-bolded numbers).
Gathered data reveals that the corrosion is not a problem with just a few suppliers, as claimed items originated from 21 different suppliers, not counting items from other Metso
locations and their vendors. Out of 47 claims, the number of claims per one supplier ranged from one to six, with twelve suppliers having only one claim. Using this information, one could deduce that the problem lies within inadequate instructions (or distribution of the instructions) to the supplier, rather than one supplier not following Metso’s surface finishing documents. As a counterpoint, one claim per supplier does not indicate systematic failure to follow the surface finishing instructions.

All in all, the claims indicate that the problem is heavily at the supplier end as the parts can corrode so quickly, within a couple of days’ storage and freight. Most likely Metso design items’ documentation and communicating our way of doing things to the suppliers are not up to the task, presently. Corroded items are usually cheap, perhaps not seen worth the trouble to be protected any better, by suppliers and our designing. Due to this, the parts are often subject to claiming, resulting in a customer that is let down, and unnecessary expenses, like logistics costs and price of new part.

There are some unknown factors regarding the claims, such as how often ocean freight is used compared to air freight, or an average cost of a Metso item in general. Another thing to consider is the sample size. Since 48 claimed items is quite negligible amount compared to total amount of items Metso processes per year, the results of the claims analysis can be prone to extreme outcomes due to the small sample size, as per psychologist Daniel Kahneman, who was awarded a Nobel prize in economic sciences (Kahneman 2011. 110-111). Although the number of claims is small, all of them create a lot of problems and workload for people involved. Also, not all relevant claims were examined because some have been lost from people’s personal emails, when they have either switched position inside Metso or are no longer working for Metso.
6 PROPOSALS

In this chapter, various means to prevent the customers from receiving corroded parts are suggested. The suggestions are based on the claims analysis, expert comments and some feedback from the suppliers regarding the claims. The proposals are divided into two categories, main actions and possible follow-up actions, that should be realized if the main actions do not improve the quality of parts through better surface finishing.

The main proposed actions are:

- Document distribution and maintaining to suppliers
- Improve warehouse’s quality control through defining corrosion and proactive inspections
- Replace Macon’s surface finishing instructions in PDMs.
- Improve DC Quality department’s processes
- Returns and stock relocation – clear instructions to prevent shipping of corroded parts
- Purchase coating thickness gauge and surface roughness gauge for the warehouse

The proposed minor actions and follow-up actions are:

- Narrow down the number of suppliers
- Refine surface finishing text on PO
- Minor changes to the surface finishing document to make it more understandable

6.1 Main proposed actions

6.1.1 Document distribution and maintaining

The main reason the suppliers provide parts with insufficient protection seems to be that they do not protect the parts according to the general surface instructions and do not take responsibility of the inadequate quality when Metso claims the parts, stating there is no instructions to follow. As this also happens with suppliers that deliver frequently to Metso, it is best to send the surface finishing instructions to all suppliers through a channel
like Pool4Tool, and demand acknowledgement that the supplier is received and understood the instructions. Although most suppliers should have the instructions, it is good to refresh their memory, especially with suppliers the company do not order frequently from, and eliminate the possibility of a vendor not having them. The responsible department in Metso should maintain the documents to suppliers when there is a new document, or a new supplier.

6.1.2 Warehouse actions

Corrosion should be clearly defined to the warehouse to eliminate the risk of the customer receiving a part of subpar quality. Today, the warehouse has instructions to be cautious about corrosion when sending parts to distant countries, but the quality should be the same for all recipients. Also, it is less confusing when the instructions are the same for everyone. Defining corrosion better helps the warehouse personnel to do the right choice, when confronted with a rusty part and a question, should they send out the part or not. Warehouse inbound could decline the rusty parts easier, and if parts corrode while in the warehouse, ultimately the parts would not be sent. When all items of the same code (or batch) are rusty, it seems to lower the bar of acceptance as the reference point will be the average rusty part. Defining corrosion also enables the proactive inspections and removal of rusty parts from the stock. Now, in a worst-case scenario, an item is ordered, and upon picking the part, it is deemed rusty, delaying the order for months because a new one needs to be manufactured. Checking on long-stored parts now and then will help keep the stock balance true (no rusty parts that would be removed from the stock anyway) and customers happier when no surprise delays happen.

Coating thickness gauge and surface roughness gauge could be a sound investment. When a new or non-frequent supplier delivers parts, the coat thickness could be then measured, to make sure it is up to the specifications and stand up to the environment. Tampere production has the gauge already, but DCE should have the tool in their arsenal as well, as they use suppliers the production unit does not. In current state of things, paint thickness on the parts varies a lot. As some design items have strict roughness demands, it is important to be able to measure them for smooth operation, but also to determine that the corrosion preventive coatings are thick enough. In a rough surface, the coating may be inconsistent or locally nonexistent due to spurs on the surface.
6.1.3 Returns

Part returns and items to be allocated to another warehouse should be inspected carefully before dispatching them. On multiple occasions, parts were moved from another Metso location to DCE warehouse and then deemed rusty by the warehouse personnel or customer, essentially transporting items for naught, burning money and resources, when an inspection could have prevented all that. Beforementioned corrective action, defining corrosion for warehouses should affect stock allocations too. Global inventory planners (GIP) sometimes call for stock allocation to even out the stocks between continents and warehouses. While doing this, they could check how old the to-be-relocated part is, instructing procurement planners to exercise special attention to those parts. Dealers returning parts should be covered with current practice, dictating that no make-to-order items (often metal plates and other metal parts) are taken back and returns are not accepted for items that dealers have ordered a long time ago. With SSO transactions however, the order date is usually not taken into accounts, though it should, because it can suggest how old the item is. Current return packing instructions for distributors tell them to repack the item using the same packaging material it came with. The instructions should tell the distributor to make sure possible VCI sheet is intact, and check if greased parts still have enough grease and apply more when needed and using the same practice to other protection methods.

6.1.4 DC Quality processes

One way to improve part quality is to improve DC Quality unit’s processes. The unit should collect claims and data about rusty parts to a concentrated list, with materialized costs, to justify needed actions to the management. Ideally all claims should be in one place to ease the data collection. The suggestion could be realized by hiring more quality engineers to the DCE. There is only one quality engineer now, leaving them with quite a lot to do, with little time to improve the processes.

6.1.5 Document replacements to PDM

Changing Macon’s old surface finishing instruction status from “Approved” to “Replaced” in PDMs should be an easy step to avoid confusion between the instructions.
6.2 Minor and follow-up actions

If the main actions do not improve part quality, the follow-up and minor actions should be looked at. DCE should consider narrowing down the number of non-frequent, non-production suppliers if they continue to have problems with the quality. They should be audited and when push comes to shove, minimize the usage of that vendor by directing the orders elsewhere. Frequent suppliers know the quality requirements better and supplier control becomes easier with smaller vendor pool.

A clarifying sentence about surface finishing to the PO texts could be in order. Instead of “Surface finishing according to instructions”, “Surface finishing according to (the latest surface finishing document code) when no other requirements in purchase order or drawing” could help DCE at least get the supplier be hold responsible about poor quality, indirectly improving quality, since suppliers want to minimize their quality costs.

Slightly changing document N11529634, Painting system D1 for steel and iron surfaces, is the last suggested action. As it stands now, protective measures for areas which are not painted are discussed in Appendix 2 in the document. The appendix lists components that are not to be painted, followed with a table about protection agents and methods for those components. The list does not, but should, include non-machined surfaces. That way all the small items would not be painted but protected using category P1.1 in Picture 6.

<table>
<thead>
<tr>
<th>CODE</th>
<th>Protected object:</th>
<th>Protection agent or method:</th>
<th>Note:</th>
</tr>
</thead>
<tbody>
<tr>
<td>All products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1.1</td>
<td>Readymade purchased components with insufficient or without any surface finishing</td>
<td>Wurth Protection Wax 0893-082 Tectyl 506 multipurpose spray Henry Protect 100</td>
<td>For lengthened outdoor stocking and overseas transportation Dry film thickness: 50 µm Wet film thickness: 100 µm³</td>
</tr>
</tbody>
</table>

Picture 6. A snippet of protection agents and methods in document N11529634
7 SUMMARY

The thesis was about finding out problems in the DCE supply chain that lead to corrosion in spare parts and customers receiving the corroded parts. In the thesis, spare part claims and surface finishing documents, along with packing instructions, were examined, and DCE supply chain, quality functions and relation to Tampere factory were explained. The proposals were done based on claims data, documents and expert statements. The thesis examined small number of claims, but there are more that were not accessible, and some customers do not claim corroded parts if the rust does not affect the part use. Corroded parts generate a lot of problems and wasted resources. Typical claimed spare part is cheap design item, with no surface finishing document linked to the drawing, and was not sent to customer by sea and had relatively small storage time.

Most spare parts are designed in a few Metso locations, with various surface finishing document relations, and are manufactured by many different suppliers, creating challenges to the supply chain. The parts are delivered to Metso warehouses via different freight modes and are stored in the warehouse, until they are sent out to the customer. Both supplier and Metso packing are done according to Metso’s packing instructions that include using VCI plastic, greases and other protection agents along with choosing correct type of package.

The drawings and POs either have surface finishing document linked to them, or they do not. It might be confusing for the supplier to follow instructions correctly, but frequent suppliers should know the instructions well. If the problem persists, refining the PO text about surface finishing and considering less suppliers could be helpful. Minor changes to the surface finishing documents and making their replacements clearer will no doubt help suppliers further, as should reminding them of the general instructions as well.

Defining corrosion for the warehouse would help the warehouse personnel send less corroded parts to the customers and enable proactive stock checks to remove bad parts from the stock. Parts with long storage time and returned parts should be re-protected before sending. DCE quality department could use extra tools to check on the parts in the warehouse and could perhaps use an extra pair of hands to improve quality processes and help with the quality engineer tasks.
SOURCES


Pitting corrosion. NACE. Read 19.11.2018 https://www.nace.org/Pitting-Corrosion/

