Degree project

Offshore cable protection

Havsbaserad kabelbeskyddning

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Summary

The market for renewable energy and an international power grid is constantly growing. In all countries, there has been a steadily increasing consumption of energy for a long time, and the need to transport electricity has been increasing ever since the electricity was invented. Countries need to be connected to each other to efficiently distribute the electricity and the shortest distance makes the energy distribution more efficient, which often is across oceans and lakes.

This project has concerned the installation, and protective methods for the offshore grid with a focus on different materials. The offshore installations are divided in two main fields, long distance connections over waters, and connections within offshore wind farms.

A subsea environment has an abrasive effect on most materials, but some materials are more resistant than others. The materials that are mostly used under water today are concrete, cast iron and, in increasing amount, plastics. The materials are evaluated with aspect to strength, life-length, reliability and environmental impact.

Snapp products of Sweden AB are a company that develop and manufacture innovative solutions for the cable protecting industry. So far they have only been operating in the onshore cable market, but their new product, that will soon be on the market, Snapp Panzar, is especially designed for subsea usage. As a part of this study the possibilities for this product are investigated. Through the use of literature, interviews and gathered test data, results have been obtained. The materials have different advantages and the main results are:

- Environmental surroundings are the most important factor when choosing material for cable protection.
- Concrete is the most environmental friendly choice, if all materials are manufactured from feedstock resources.
- Polypropylene has a life time exceeding the requirements for cable protection pipes and the ageing process affect the properties relatively unnoticed.
- Snapp Panzar will successfully withstand the strains it is exposed to

The results are considered overall to be reliable, but specific tests on the plastic blend that the company uses are recommended. Interviews and conversations with experienced people in the business supplement and verify the results that have been established.
Abstract

The market for renewable energy and an international power grid is constantly growing. This project has focused on the installation and protection methods for offshore power cables. Long distance cables over e.g. oceans and smaller distances within offshore wind farms.

The focus is on three different materials for the protection task; concrete, cast iron and plastics. These materials have been evaluated in aspect to strength, life-length, reliability and environmental impact.

Snapp products of Sweden AB have developed a cable protective pipe of polypropylene for offshore usage. This product and its opportunities are thoroughly investigated.

Keywords:

Offshore, Cable installation, Polypropylene, Comparison, Polymer, Concrete, Cast iron, Environmental, Lifelength, Pipes
Preface

This report is a degree thesis at the Linnaeus University - Faculty for mechanical engineering, Växjö, Sweden. The thesis covers 15 Swedish University credits and is executed by two students.

This project has emerged through a product, Snapp Panzar, which the company Snapp Products of Sweden AB has recently developed.

Company supervisor, Stefan Svensson is thanked for the time he spent on assistance with arranging meetings and study trips.

Material Expert, Izudin Dugic as supervisor for the project, and plastic expert, Leif Pettersson as external mentor, are gratefully thanked for their knowledge contribution to the project; they have been of great importance to the development of the report.

Further thanks are directed towards the diving team in Karlskrona, Sweden that took the time to meet and explain their work.
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IX

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1. Introduction

In this chapter a presentation of the background to the growing market for renewable energy and an international power grid is made. Further on the challenges and purpose with the project is discussed and presented.

1.1 Background

In all countries, mainly in the far developed counties, there has been a steadily increasing consumption of energy for a very long time [1-3]. The consumption is expected to keep growing. Inevitable this has, and will keep on, lead to unwanted environmental impacts, and in addition the depletion of the limited fossil fuels is accelerating [4].

The European Union, together with several governments in Europe has been setting striking guidelines regarding their energy production and the development of renewable energy sources [5-7]. One example is the UK government that in 2011 stated that in the year 2020, 15% of their total energy production will consist of renewable energy [2].

To ensure that the renewable energy sources are being used efficiently, a global connected grid is needed, across oceans and lakes, over rivers, to islands etc. The market for a global grid is inevitably following the growing interest for renewable energy [5, 7].

The offshore wind power industry is one of the currently most relevant kinds of renewable energy. The reason is that the best onshore sites for wind farms are rapidly being used taken, another even stronger reason is that the winds at sea are generally stronger and more reliable [2-5]. In figure 1.1 the growth of both onshore and offshore wind power is illustrated, also containing the expected growth until year 2020.
It is generally preferable to construct any offshore facilities far from coastal regions due to minimizing of environmental impact and an undisturbed landscape. It is also important to minimize the interference with the sea traffic, fishing industry etc. [3, 7, 9, 10]

All these active trends lead to an increasing need of a grid of power cables on the seabed. The deployment of this grid is a market that is naturally following the increasing popularity of the earlier mentioned markets [2, 5, 9].

Snapp Products of Sweden AB is a family company that focuses on the development and manufacturing of cable protective pipes for the power and construction industry. The material Snapp uses is recycled plastics, mainly from the car industry. This leads to their competitive prices, but also makes the company environmentally aware for a sustainable society.

Snapp is a small actor on the market for cable protective pipes, the use of their product is mainly motivated in specific situations. There are many other actors on the market with different solutions for protection of cables. The pipes can be constructed of many different materials, often expensive materials are used to provide good mechanical properties [11, 12].

1.2 Problem discussion

The need to transport electricity has been increasing ever since the electricity was invented. Many countries have varying energy consumption; they have a desire to buy electricity, when the demand is high, and to sell when the demand is low on the national market [13]. When a power outage occurs in a first world country, the repair work starts immediately and every second is of great economic importance [7, 13].

Figure 1.1 Expansion of wind energy installations [8]
Power cables at sea are generally high voltage cables that transport large amounts of electric power constantly. A failure somewhere in an offshore grid can result in long-time interrupted supply of power due to the unfavorable environment and the difficulties to localize and repair the failure [7, 10, 14].

It is preferable that the maintenance and repair work is kept to a minimum, and therefore some kind of cable protection is often used. The solution can be as simple as burying the cable in the seabed, when the condition are favorable. When the conditions are rough, for numerous reasons, a protective solution is needed [7, 14].

The solutions that are available today are used in different situations and a combination of different protective solutions is often the best method of choice. The different solutions also consist of different materials to fulfill their specific task [2, 7, 10, 14, 15].

Snapp has developed a new product that is planned to go into manufacturing in the end of 2014. It is a cable protective pipe named Snapp Panzar, which is especially designed for the offshore market. This project is an investigation of the offshore cable protection market, with focus on materials, formulated into two questions.

- Which material is best suited, for the different applications that exist today, for long-time protection of electric cables under water, with aspect to costs, reliability, operation and environment?
- In which cases are Snapp Panzar advantageous compared to existing solutions?

1.3 Purpose

The purpose with this degree project is to determine which areas within offshore cable protection that Snapp’s pipes are suitable for. The focus will mainly be on their upcoming product Snapp Panzar. The materials strength properties will be analyzed to be able to evaluate if the pipe is suitable for use in offshore applications. Further the advantages and disadvantages for Snapp’s pipes compared to similar solutions of cast iron or concrete will be examined and a suggestion for which pipe is suitable in different situations will be made. It will also be explored if the plastic blend that is used today is optimal for underwater use.
1.4 Objectives

To find out which pipes that are best suited as mechanical protection for the cables, theoretical research will be fundamental in this report. Information from active companies within the field will be gathered. Results from test facilities and impartial agencies are other important sources of information that will be analyzed and considered in this comparative report.

1.5 Limitations

This report will consider cable protecting pipes of cast iron, concrete and plastics. Also different plastic blends will be considered, but mainly the blend that Snapp uses. The focus will be on technical properties and price. This report will contain information about how the different topographies of the seabed in northern Europe affect the installing of the cable, using the different methods.

Smaller oceanic distances and the use within Wind Farms will be considered in this study.

The test equipment will set some limitations to the study. Tensile strength and Impact strength are the properties that are possible to test. Life endurance, temperature influence, corrosion and abrasion will not be tested within this study, but a theoretical study will be made.
2. Theory

Protecting cables in subsea environments is a complicated task. The circumstances are unique in every situation; geological properties, topography, harbors, sea routes, currents, temperatures are factors that can influence the method of choice, and the route the cable should take.\[7\]

Theory relevant to this study is regarding material properties like strength (tensile and impact), life length theories, such as abrasion, Corrosion etc. The different materials have been used for creating different solutions with varying strengths and weaknesses which will be described \[16,17\].

2.1 Offshore cable installations

When it comes to offshore cable installation, there are many different environments that need to be considered. The two main fields of application for the offshore cable industry is connections over oceans, lakes or similar; and all connections regarding offshore wind farms \[2,5,7\].

2.1.1 Distant subsea cable connections

The installation of cables in subsea environments is a very important task, without a functional grid, the harvested energy can easily be lost. Countries need to be connected to each other to efficient distribute the electricity and the shortest distance makes the energy distribution more efficient, which often is across oceans and lakes.

The installation of subsea cables has been around for a very long time, since the energy consumption has steadily increased during the years, the cables installed 50 years ago or more are often under dimensioned. The amount of power they can transport are not sufficient, therefore additional cables over the same oceanic distances are occasionally called for \[5,10,18\].
2.1.2 Installation of subsea cables

The methods for installing cables on the seabed that are frequently used are: [7]

- Water-jetting
- Milling
- Plowing
- Covering

2.1.2.1 Water-jetting

Water-jetting is the most desirable method when bury cables below the seabed. It is an effective and safe method that is used when the seabed is sandy and muddy. The risk of hurting the cable is minimal. Hydraulic water-jets pumps seawater through nozzles which makes the seabed dissolve and the cable that already has been put on the seabed will sink and automatically be covered when the bottom material returns to its original position. Picture of water jet equipment is seen in figure 2.1 [7,10]
2.1.2.2 Plowing

Plowing is simply a mechanical method where a plow of 10-30 tons is dragged behind a ship. The cable is led through the plow and both the digging of the ditch and cable installation is made in the same operation. This causes a risk of hurting the cable which needs to be considered when choosing method. An advantage with plowing is the possibility to be used when encountering a harder seabed. Picture of plowing equipment can be seen in figure 2.2 [7,10].

![Plowing equipment](image.png)

*Figure 2.2 Plowing equipment [7]*

2.1.2.3 Milling

Milling is an expensive and time consuming way to dig down cables. It is only used when the seabed is very hard like solid rock. Because of the operational cost it is the last option and used where special problems may occur e.g. close to land where covering of the cable is not possible in a safe way. The machine consists of a rotating blade that cuts a ditch in one operation [7, 18].
2.1.2.4 Covering – concrete mattress

At very exposed locations where the possibility to dig down the cable is limited, it is instead covered by concrete mattress like the one in figure 2.3a. Figure 2.3b show a detailed picture of the connections between the concrete blocks. Figure 2.3c show the metal reinforcements that are used between the blocks in the mattress.

The concrete mats are placed with help from cranes and submarine cameras. In some cases also half concrete pipes are used to cover the cables \cite{7,10,14,18}.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{concrete_mat.jpg}
\caption{Concrete mat used as cable protection \cite{14}}
\end{figure}

2.1.2.5 Covering -rocks

Covering is sometimes done with crushed rocks, sometimes the masses from plowing or milling is used to cover the cable. This method is normally used when the installation is made close to shore. The most common situation is that the masses are transported out, and then poured in position over the cable with the help of long pipes from the ship \cite{7}.

2.1.2.6 Covering –sand and rock combination

This method is mostly seen in the middle to southern parts of Europe. A furrow is plowed or water-jetted; depending on the bottom topography. Then sand is transported out at sea and poured in over the cable that has been placed in the furrow by a diver, or remote controlled vessel. The purpose with the sand is to protect the cable from the sharp rocks that is later filling up the furrow. In addition, a cloth is used to keep the sand and rocks separated. This method is illustrated in figure 2.4.\cite{12,19}
1. The furrow is plowed, and the bottom is filled with sand to create a soft bed for the cable in the furrow.
2. The reinforced cable is placed in proper position in the furrow by a diver or remote controlled vessel.
3. Sand is scooped over the cable followed by a cloth made of non-woven fabric.
4. Finally masses of crushed rock are used to fill the furrow (in favorable situations the masses plowed up in step 1 can be used).

This method is a very time-consuming and costly process, especially the sand that is both expensive and cost-inefficient to transport [12, 19].

2.1.3 Offshore Wind farm connections

Within a wind farm there are several cable connections between the different wind turbines and also to the different substations within the park. All these need secure cable runs. From the wind turbine the cable takes its path within the foundation of the turbine down almost to the bottom of it, still inside the foundation, then through a J-tube [21,22] where it is connected to the grid on the seabed. From the point where the J-tube ends, the cable is uncovered between 10 and 15 meters before it is buried under the seabed and is drawn to the next
wind turbine\textsuperscript{[23,24]}. A picture of the scenario is shown in figure 2.5. The distance when the cable is uncovered also needs to be protected somehow and there are some different solutions for this on the market\textsuperscript{[21,22]}.

![Wind turbine](image)

*Figure 2.5 Cable from offshore wind turbine*

2.2 Materials

A subsea environment has an abrasive influence on most materials, but some materials are more resistant than others. The materials that are mostly used under water today are concrete, cast iron and occasionally plastics\textsuperscript{[2,12]}.

2.2.1 Cast iron

Cast iron normally contains 3-4\% Carbon (C) and 1-3\% Silicon (Si). The common types of cast irons are:

- Grey Cast Iron
- Ductile Iron
- White Iron
- Malleable Iron
On the market there is almost exclusively Grey cast iron and ductile iron. Grey cast iron is the most common casted material due to favorable flowability, easy processing, low price and a reliable result [16].

2.2.1 Grey Cast Iron

Grey cast iron has poor ability to change shape; the elongation is low as well as the tensile strength. However a good ability it has is to withstand pressure. A stress-elongation diagram for cast iron is shown in figure 2.6, the vertical axis represent stress and the horizontal axis represent elongation [16].

![Stress-elongation diagram for cast iron compared to steel](image)

Figure 2.6 Stress-elongation diagram for cast iron compared to steel [16]

Further on the modulus of elasticity is about 100000 [N/mm²] which is about half of steel. The reason for this is the presence of graphite with a very low strength which makes it unable to withstand almost any loads. This makes the stress distribution very uneven and the ferrite-perlite that has an E-modulus equal to steel has to carry the whole load with the result of a lower total E-modulus [16]. Cast iron is used in many applications; in figure 2.7 is a pressure pipe of cast iron that has been revealed for reparations.

![Pressure pipe of cast iron](image)

Figure 2.7 Pressure pipe of cast iron [25]
2.2.2 Concrete

Concrete is a natural material that contains mostly of rock materials or smaller parts as sand and stone. As binder in the concrete there is 2-6% of water and generally 10-16% of cement powder. Often a small amount of additives is added to improve the properties of the material.

Concrete has a very long sustainability, in theory several thousands of years. The compressive strength is very high while the tensile strength is quite bad. To improve the tensile strength rebar are added. The great durability and resistance of concrete makes it a perfect material to be used in places with very high wear. It is important to consider the composition of the concrete as well as the amount of reinforcing rebar to achieve a material that fits for its purpose [26].

The sustainability in seawater is very good, if the right concrete compound is used it will last for 50-100 years. But of course also concrete is attacked and starts to decompose. The material will suffer from sulphates and chlorides. The sulphates loosen up the surface and the chlorides make the rebar rust. Because of this it is important to use cement that is resistant towards sulphates to resist the attack on the material. Another thing for achieving a good sustainable material is to consider the amount of water in proportion to the cement. The water cement ratio should be water/cement < 0.4. It is also important to have sufficiently thick layer of concrete to protect the rebar [27].

2.2.3 Polymers

The polymer is a chemical often organic substance that consists of long chain-like molecules. Polymers have a low modulus of elasticity, meaning they can withstand high loads in short periods of time without plastic deformation. One negative aspect of low modulus of elasticity is that the polymers creep, meaning that the deflection can be permanent when a load is applied under long time [28].

Polymers are generally more sensitive to temperature variations than other materials like metals etc. Therefore polymers and polymeric blends are generally tested in different temperatures to clarify their properties for the specific application. It is rare that a polymer can be used in environments with temperatures over 200° C [28].

The advantages with polymers are often the possibility to create a specific material for the certain application. The molding processes are often very favorable, even when constructing more advanced shapes. The elastic deflection
possibilities can be used to make snap-assembly solutions, which are very cost-effective. The polymers often have good surface qualities, no finishing operations e.g. polishing is needed. Polymers are also corrosion-resistant\textsuperscript{16,28}.

The most commonly used polymers are polyethylene (PE), (also known as polyethene) and polypropylene (PP), (also known as polypropene)\textsuperscript{29,30}.

2.2.3.1 Polyethylene (PE)

Polyethylene is manufactured through polymerization of Ethylene and a proper catalyst. PE is the most common plastic; it is normally divided in LD-PE (low density) and HD-PE (high density). PE is usually the choice in the food industry. PE is characterized by high impact strength in a wide temperature range, chemical resistance, low price, poor creeping resistance, bad weather resistance etc.\textsuperscript{29,30}

2.2.3.2 Polypropylene (PP)

Polypropylene is a semi-crystalline thermoplastic that exists in a large amount of different types. PP has high fatigue strength and is resistant towards most chemicals. The mechanical and electrical properties are kept even in water. The material becomes brittle under \(-20^\circ\) C and has an ability to be attacked by oxidizing acids. PP is suitable for molding, injection molding, thermo forming and extrusion. The glass transition temperature, \(T_g = -10^\circ\) C and the melting temperature is \(165^\circ\)C \textsuperscript{16,28}. See appendix 1 for more thermal properties of the polypropylene.

2.2.3.3 Elastomers

The term Elastomers comes simply from elastic polymer. Elastomers are polymers with high elastic stretch ability and a quick springback to the original shape. Elastomers can have elastic modulus as low as \(10^3\) [GPa], that increase with temperature, all other solids show a decrease\textsuperscript{28,29}. Elastomers can be used in polymer blends as compatibilizers\textsuperscript{31}.

Sometimes elastomers are added to blends and referred to as additives; they serve as impact modifiers in the blend. The most common procedure is that Polypropylene is the basic ingredient, and then the elastomer is added. Finding the perfect amount of the elastomer added in the mixture is often a time-consuming process\textsuperscript{29,30}.
2.2.3.3.1 Ethylene propylene diene monomer (EPDM)

EPDM is a relatively inexpensive synthetic rubber belonging to the elastomer family. It is used in many applications like tires, coatings and for repairing roofs when in liquid shape. It is also used as a compatibilizer when mixing e.g. PE and PP plastic because of their bad mating in original shape. The material is very resistant to heat, ozone, steam and UV-light among some things and is also good at withstand different chemicals and is stable in saltwater. EPDM is very flexible and mixed with e.g. PP plastic it makes the product more flexible [31-33].

2.2.3.3.2 Polyurethane (PU, PUR)

Polyurethane is a very wide group of materials, all from plastic materials to soft elastomers and foam-like materials can be polyurethanes. The wide range gives the opportunity to adapt perfect polyurethane to the specific application even more than other plastics. Working with polyurethane requires a lot of experience and certain chemical experience. When high quality is required for an elastomer, some kind of polyurethane can generally be suitable. Polyurethanes are a more expensive alternative to other polymeric choices [24,29,30].

2.2.3.4 Additives

The properties desired for a product can be met simply by polymers; however, the introduction of additives to the polymer blend can be very useful. The properties can often be improved even further; some special combination of features can easily be obtained with additives. In some cases it can be much cheaper to use additives to provide the same properties to the blend [30].

The most common method when adding additives to polymers is in shape of powder, paste or granules. Each addition process is unique, though it is common to mix the additives below the softening point of the polymer to ensure that the additive spreads well. There are other ways of mixing the additives, before the polymers are mixed, with polymerization in a few steps, also it is possible for additives to be added during processing, like blowing or molding [29,30].

2.2.3.2.3 Glass fibers

Glass fibers are usually added to the mixture in small amounts to reinforce the plastic, and improve the mechanical properties. Depending on the amount, the addition of glass fiber can result in a brittle compound. Glass fibers are the most commonly used reinforcement [30].
2.2.3.2.3 Carbon black (CB)

Carbon black (CB) exist in two shapes regarding polymer blending, one as a pigment material and one as a filler, the difference is the depth it affect the blend, and the size of the particles. The most commonly used is CB the pigment material, only that will be considered in this report \cite{30}.

CB is the most widely explored additive regarding PE/PP/EPDM-blends due to:

- Low cost
- Grade diversity
- High reactivity
- Weather resistance

CB is mainly used as additive in polymer blends to provide better weather resistance for the blends; UV-resistance is the most important. These features are desirable in the car industry and that is the reason why CB is so widely explored. The amount of plastic in a car is steadily increasing due to these suitable properties, and also the low weight and low price are attractive features in the car industry \cite{29,30}.

CB is a manufactured additive and has been in use for over a century, not as an additive to polymeric blends but in other applications. It consists of approximately 97% pure carbon, minor differences can be obtained, depending on the manufacturing process. The most common usage for CB is as an additive when manufacturing tires along with other plastic and rubber details in the car industry, to provide UV-resistant details. CB is also used in inks, paints, coatings etc. \cite{34}

CB possess high surface- to volume ratio which makes it very favorable in blending processes. High surface- to volume ratio means that an average particle of CB is shaped so that it has high surface area in relation to the volume. This means that more surface area of CB-particles are able to chemically react with the other ingredients in the blend. This is also called high reactivity \cite{29,30}.

There are two different ways to manufacture CB, partial combustion or thermal decomposition of either gaseous or liquid hydrocarbons. This decomposition is made under controlled conditions, which can be adjusted to create the CB with the desired properties. Properties that can be controlled by adjusting the decomposition conditions are e.g. specific surface area, particle size and structure, electrical conductivity and color \cite{30,34}.
2.2.3.5 Polymeric blending

The polymeric component available today are many, it is difficult to select the perfect composition for the special situation. A lot of time and funding are required to find the perfect blend, meaning it is only motivated when the specific market is promising enough to eventually pay back the investments made in the blending research process [28].

The reason to blend polymers is usually to create a plastic with the exact desired properties to the best price possible. Properties that can be modified with changes in the polymeric composition can be tensile strength, impact strength, modulus, flammability, melt flow index, conductivity, color, UV-resistance etc [16,28,31].

2.2.3.6 Plastics

Plastic is a material that consists of polymers and additives. The polymer is a chemical often organic substance containing of long chain-like molecules. The additive is a substance that is added to the polymer to improve a property e.g. reinforcement, UV-stabilizer or as protection against fire. Plastic properties are varying in a wide spectrum, due to the endless possibilities to change the ingredients, or the manufacturing process. The general features that can be established for the majority of the plastics that are on the market today are listed below [16,35,36]:

Advantages

- Low density
- Good corrosion resistance
- Good insulation properties for heat and electricity
- Good sound- and shock resistance

Disadvantages

- High thermal expansion
- Bad resistance against heat, UV-radiation and chemicals
- Static charge
2.2.3.7 Plastic Classifications

Plastic material is divided into two main groups, thermoplastics and thermosetting plastics. Thermoplastics can be recycled through melting and reshaping which is not possible for the thermosetting plastic. The plastic material treated in this report is semi-crystalline thermoplastic which gives the following special properties \[16,35,36\].

Advantages

- Stiffness
- Wear and abrasion resistance
- Chemical resistance
- Impermeable for moisture and most gases
- Easy processing

Disadvantages

- Stiffness and creep modulus impaired with a higher temperature
- Not transparent
- Mold shrinking

2.2.3.8 Melt flow index (MFI)

The manufacturing possibilities are a very important aspect when comparing materials, regarding polymer blends, Melt flow index (MFI) is commonly used. MFI is a measure for the blends ease of flowing when melted, this is important when the blend is shaped through injection molding or injection blowing \[29,37\].

A blend with low MFI can usually only be used in simple molds, with wide flow channels. However, low MFI is not always negative, though the basic rule is; low MFI = high mechanical strength properties. Many attempts are usually made before a desirable blend with an acceptable balance between MFI and mechanical strength is found \[37\].

MFI is corresponding to the molecular weight of the blend, high MFI means low molecular weight. It is sometimes explained as a measure of the melted materials ability to flow under pressure. MFI is sometimes referred to as MFR (melt flow rate). In some literature MFI is divided into melt mass flow rate (MFR) and melt volume flow rate (MVR), most often the melt mass flow rate are the only kind considered and referred to as MFR or MFI \[30,37\].
2.3 Corrosion

Metals are found in nature as compounds of various kinds like sulfites, sulfates, oxides, chlorides, carbonates, etc. When producing the metals it is done by chemical reduction when energy is supplied to the material. Because the metal is now not in its natural state it wants to return to this through oxidation [16,17].

Corrosion means fretting, the material that is exposed to corrosion is dissolved through chemical reactions with the environments. When a material corrode it strives towards its basic state, which often is more stable than the current state. Generally it is said that only metals corrode, but theoretically many other materials can corrode as well, even plastics and ceramics [17].

Corrosion can occur in both air and water, and also in other mediums. Some materials are very resistant to corrosion in certain mediums. For corrosion to occur some kind of electrolyte must be present and electrons must be able to travel from an anode surface to a cathode surface [16,17].

2.3.1 Corrosion types

There are several types of corrosion that can occur in many types of materials. The definition of corrosion is similar to degradation. When it comes to corrosion in plastics it is similar to that of metals, it is usually called aging [16].

2.3.1.1 Uniform corrosion

Cast iron is exposed to high corrosion in all media. In most cases, the corrosion attacks evenly over the entire surface and is called the uniform rate of progressive reduction. In salt water the corrosion is 0.025-0.1 mm / year. Even so-called pitting can occur when the attack on the material occurs in a limited area. The speed of the attack is difficult to determine as it varies greatly but can be 10-20mm/ year [16,17].

2.3.1.2 Pit corrosion

Pit corrosion is local corrosion that leads to attacks on the material with narrow width but a significant depth. Pit corrosion is also occasionally referred to as spot corrosion [16,17].
2.3.1.3 Graphite uncovering corrosion

On cast iron graphite uncovering corrosion may occur which means the iron is dissolved completely in the material and only graphite and cementite remains. The material is then so brittle that it can be easily scraped apart by a sharp tool or a sharp stone[^16][^17].

2.3.1.4 Galvanic corrosion

Galvanic corrosion basically means that two different metals are in contact with each other. Either directly or through a medium, called electrolyte. Different metals have different positions in the electrolytic voltage chain which means that there will be a difference between the two that leads to that the less precious metal of the two is positive (anode) and the more precious becomes negative (cathode). The negative voltage in the more precious enables electrons to emit to the electrolyte surrounding the metals. Because the metal is negatively charged, it has a surplus of electrons and the process is done very easily. However, the medium surrounding the materials have to include something that could receive the electrons, for example, loose oxygen. This departure of electrons does not harm the material because new electrons constantly are received from the anode. Instead, it is at the less precious metal the problems occur where it is a positive voltage. The positively charged atoms will become ions. The volatile OH⁻ ions in the medium are attracted to the anode and combines with the ions formed there. The product of this is rust[^17].

See figure 2.8 for an illustrating picture of the process. A picture of the electrochemical voltage series is shown in appendix 2.

---

[^16]: Reference 16
[^17]: Reference 17

Figure 2.8 The nature of the electrochemical corrosion
2.3.1.5 Ageing processes of polymers

There are two types of ageing in polymeric materials, chemical and physical. Physical ageing leads to a structural change in the polymer which is reversible and can be restored through e.g. heat treatment. Chemical ageing is irreversible changes and can of course not be restored. The different chemical ageing processes is divided into what causes the change. They are:

- **Thermal degradation** - The polymer brakes down by heat.
- **Thermal-oxidative degradation** - A combination of heat and an oxidant like oxygen, ozone or chlorine.
- **Hydrolysis** - Degradation through a chemical process with water.
- **Chemical brake down** - Direct attack from a strong acid or base.
- **Degradation of radiation** - From e.g. ultraviolet light.
- **Mechanical brake down** - This happens when the polymer is exposed for fatigue loading.
- **Biological brake down** - An attack from microorganisms, enzymes or insects.

It is also very important to consider different combinations of these attacks on the polymer due to the accelerating speed of degradation of the material when it is exposed to several degradation processes at once [35].

2.3.2 Protection against corrosion

For the engineer it is very important to consider several aspects when designing against corrosion. At first choose material with concern of the environment the construction is placed in. Consider where the corrosion will be biggest and adapt the construction after this. In pipes it is important to think of the aggressiveness of the medium that will flow through the pipes. Also the operating conditions in the pipes like pressure and temperature should be well thought of [17,38].

2.3.2.1 Material treatment – cast iron

Painting of a material has been used during several thousands of years as a way to hold off the corrosion of a material. It is useful in many constructions but often needs repeatedly maintenance so in a long-term perspective it could be very expensive. Another useful way to protect the material is through coating of the surface with different kinds of polymers, both rubber and plastic. The
polymers doesn’t corrode in the same way as other materials that are affected by oxygen and humidity and are destroyed through the electrochemical process. Instead it is different chemical processes that brakes the polymers and it is therefore important to think of what kinds of chemicals and chemical processes that exists and could appear in the environment that is current\cite{17}.

2.3.2.2 Material treatment – concrete

To avoid degradation of the concrete it is important to use sulphate resistant cement. The reason for this is the sulphates ability to dissolve the surface of the concrete which makes it possible for chlorides to attack the armory of the concrete\cite{27}. Another way to protect the concrete is to strengthen the surface with fibers, for example Sisal originally from a tropical plant \cite{39}. The important thing is to make sure the concrete stays intact as long as possible to avoid corrosion on the metal reinforcements that is the main reason for destroyed concrete structures \cite{27}.

2.3.2.3 Material treatment – plastic

As mentioned earlier, plastics are normally resistant to corrosion; but they can be affected by ageing. Plastic blends can however be filled with metal powder as an property increasing additive leading to the possibility of corrosion attacks on the metal particles, which leads to weakening of the material. When small particles in a plastic blend corrode it can be catastrophic, but it can also go unnoticed, depending on the situation, the loads, temperatures, adhesive wear and of course depending severely on the blend. The corrosion and ageing resistance all depends on the use of right blend in right situation \cite{30}.

2.4 Environmental aspect

The environmental issue is one of the biggest challenges in the world today. The question is in top of many countries agenda and the high priority is to lower the effect of global warming \cite{40}. The use of energy needs to be lowered and one large energy consuming sector is of course the industry. One way for the industry to lower its environmental impact is to choose materials that has a less e.g. carbon oxide emissions during manufacturing but also when in use in its application. The most environmental friendly option is of course to recycle material \cite{41}. 

Niklas Svensson, Martin Holmberg
2.4.1 Cast Iron

The manufacturing of cast iron consumes a lot of energy. The heating temperature when melting the raw material is high and the energy consumption with that as well. The quantitatively largest emissions from manufacturing of cast iron are carbon oxide. Both from when the ovens are heated and fossil fuels are consumed and from emissions from the process. The relative consuming of energy will not seem to decrease much the coming period because of the industries modern manufacturing methods [42].

More research needs to be done in this area to make any great successes. Of course there are companies that has not invested in the most modern machineries and by that also has a higher emission of e.g. carbon oxide. The only way to achieve a substantial reduce of the emissions during manufacturing is to use recycled iron. This is done by a remelting procedure and the result is a product with equally good properties as the original products [42].

2.4.2 Concrete

Concrete is recyclable to 100% which makes it very good from an environmental point of view. The only real issue for now is the carbon dioxide emission that occurs during the so called calcining process when manufacturing the cement. There is for now very little that could be done to lower this emissions but the concrete also takes up carbon dioxide during its lifetime. This process that is called carbonation could be described as the concrete way back to its origin condition. Work is in progress to achieve a zero state when it comes to emission/intake of the carbon dioxide [43].

2.4.3 Plastics

Today 8% of the raw oil is used in the plastic industries, roughly half of it for the manufacturing and the other half to plastic materials. Around 50% of the plastic is today used in disposables, packages e.g. 20-25% is used for pipes, conduits etc. meaning for long-life applications. The rest are in the fields for consumer products like vehicles, furniture, electronics etc. [44,45]

The different polymers vary in CO₂ emissions due to variation in carbon content and manufacturing processes. Generally plastics CO₂ emissions lie between 2-4 kg / kg polymer in feedstock manufacturing. Polypropylene is generally on the lower part of the scale [44].
In Sweden around 30% of the plastics are recycled and the main part of the remaining 70% is converted to energy through combustion. There are two kinds of recycling for plastics; mechanical and chemical. Chemical recycling means that the polymer chains are broken down to smaller units through heat or chemical processes, the units can then be recycled as raw materials. Mechanical recycling means that the plastic parts are washed, sorted, and milled, the chemical structure remains unchanged.

The mechanical recycling consumes a lot less energy than the chemical recycling process. The problem is to separate and clean the plastics from impurities which often lead to worsen properties of the recycled plastic. Mechanical recycling is divided into “closed-loop recycling” were the plastic keep its quality and properties, or “downgrading” which emphasises that the quality decreases [44].

2.5 Testing methods

When testing polymers it is the same as testing for any material, it is tested with respect to well-known standards. Following chapter explains classifications of plastic pipes and some testing methods.

2.5.1 Classification of pipes

There are three standards in Sweden that decides separately or together how cable protecting pipes is going to be constructed [46]. They are “EBR kj 41:09” [47] that treat mechanical dimensioning of cable protectors [48]. Further on, there is “Swedish standard 424 14 37” [49] that consist of demands for impact load and ring stiffness strength [50]. These two together form “SPF verksnorm 5200” [51] which is a norm from the Swedish plastic union and this gives the opportunity to get a certain classification of the manufactured pipes. There are three levels for plastic pipes, SRN- protection in normal conditions, SRS- protection in difficult conditions and SRE- protection in extra difficult conditions [46].
2.5.1.1 Strength tests

To achieve the classification two tests have to be made, impact load strength and ring stiffness strength test. The tests are easily conducted. The impact test implies that a spear-shaped object with a certain mass is dropped from 1 meter. For a pipe to achieve SRS - and SRE - class it needs to withstand a spear impact with a mass of 10kg as in figure 2.9.[52]

![Figure 2.9 impact test (for SRS – and SRE – classification)](image)

The test for ring stiffness means that the pipe is pressed together and the elongation is measured. The pipe needs to withstand a specified force before reaching a certain elongation in proportion to total diameter of the pipe.[52]

2.5.2 Melt flow index (MFI, MFR)

A certain amount, normally 5-10 grams of the blend, in milled form, is placed in a testing machine, similar to an injection molding machine. The sample is compressed with help of a piston, followed by heating until melting temperature, which differs between polymers. Finally a specified force is applied to press the sample through a small die. After a certain time the amount of the sample that has been pressed through are weighed.[37]
The standardized unit for MFI-measure is \([g/10\ \text{min}]\) which means the mass in grams that has been pressed through a 2 mm diameter die under 10 minutes. Usually a few additional tests are carried out were the following parameters of the test are changed:

- Various loads
- Different piston positions
- Different temperatures

The reasons to make the different kind of tests are to favor comparisons of other materials and to provide knowledge regarding the differences in e.g. viscosity so that the most suitable manufacturing method is being used\([37,53]\).

2.6 Life length testing

It could be difficult to calculate the life length of plastic because of the lack of experience and data. A requirement of a life length and a stable plastic structure up to and even over 50 years could be needed in some applications and there are few commercial plastics that have been in use for even half that time. And also many new materials have been introduced to the market with new capabilities which makes it even harder to predict the behavior of the material over time\([35]\).

Many factors affects the lifetime of plastic pipes. The three main categories are material factors, environmental factors and loading factors. Examples are shown in figure 2.10\([54]\). Since so many plastic materials exist with different compounds and the environmental factor is of such large importance test should be adapted for the right compound in the right environment.

![Figure 2.10 Factors affecting the lifetime of plastic pipes](image-url)
2.6.1 Testing methods

Most often a life length longer then there is possibilities to test is required. To come around this problem the method is to test the material in a higher temperature then it will be exposed for during normal use. Under the circumstances that the same degradation process is used during the test as it will be exposed for when in real use there will be a relation between time and temperature that can be used in a diagram to find out how long time the polymer can be in use before reaching a certain level of degradation. Many tests is needed at different temperatures to receive a reliable diagram\textsuperscript{[35]}.

2.6.2 Arrhenius equation

Arrhenius equation (eq. 1) is used to predict the lifetime of the material by extrapolation of the test values. An easy way is to place the data in a diagram where a straight line is received with slope $\frac{E}{R}$. It is then easy to find out any lifetime at a certain working temperature\textsuperscript{[35]}.

\[
  k = A e^{-\frac{E}{RT}} \quad \text{(eq. 1)}
\]

Where $k$ is the reaction speed, $R$ is the general gas constant, $T$ is the absolute temperature, further on, $A$ is a constant that depends on the possibilities that two molecules will collide in the exact right position. After integration and logarithms the equation results in following \textsuperscript{[1.8]}.

\[
  LN(t) = \frac{E}{RT} + B \quad \text{(eq. 2)}
\]

This gives $t$ which is a value of the level of properties that remains in the material.

This ends up with a diagram as in figure 2.11 where it’s easy to find the life length of the material compared to the temperature it is exposed for.
2.6.3 Temperature index

Another data that could be of interest is the temperature index which gives the maximum working temperature a material can have without having a degradation of properties more than 50%. The testing procedure is the same as above and the result reflects the materials ability to keep its properties during normally 50000 hours at a certain maximum temperature.\textsuperscript{35}
2.6.4 Material specification

When a new product shall be developed it is of course easier to know the material requirements before any tests are made on a special material. If it is known which times and temperatures a material are exposed for it is easy to calculate a time-temperature requirement for the material from this knowledge.

These test methods are well known but leaves no guarantee that the material will meet the requirements that it has been tested to manage. Changed environment from the test procedure together with mechanical loads can affect the material in a negative direction. Many tests at current applications are preferred to be sure of the data and life length of the material \[35\].

2.7 Mechanical strength theory

There are many different properties that need to be considered to fully define the strength of a material. The theory for strength regarding static loads and impact loads are explained, resistivity and conductivity are also mentioned \[28\].

2.7.1 Tensile strength

Tensile strength is materials strength in linear direction under a short period of time. It is normally determined by yield strength and ultimate strength. Yield strength is determined by the load that the test specimen can withstand without plastic deformation more than 0.2% occurring. Ultimate strength is determined by the load the test specimen can be exposed to without breaking.

Material strength is determined by the amount of newton it can withstand per square millimeter and the unit is \([N/mm^2]\). If the force is known, it is easy to calculate the mass a material can withstand by the following formula: \[55\]

\[
m = \frac{F}{a} \quad [\text{kg}]
\]  
(eq. 3)

2.7.2 Impact strength

Impact strength is a materials ability to withstand hits or impacts. Elastic material e.g. rubber usually have good impact strength, while brittle material like glass or ceramics are easily broken by impacts \[56\].
Modulus of elasticity, ability to distribute forces, volume, and yield strength is parameters that affect a materials impact strength \[^{56}\].

The magnitude of the impact is depending on the translational energy and the area that is affected by the impact. Translational energy is calculated by multiplying the mass of the moving object with the velocity of the same object as seen in eq. 4 where \( p \) is the translation energy, \( m \) is the mass and \( v \) is the velocity \[^{57}\].

\[
 p = m \times v \quad \text{(eq. 4)}
\]

The velocity of an object can be calculated if acceleration and distance are known by eq. 4 where \( v \) is the velocity, \( v_0 \) is the origin velocity, \( a \) is the acceleration and \( s \) is the distance:

\[
 v^2 - v_0^2 = 2 \times a \times s \quad \text{(eq. 5)}
\]

### 2.7.3 Resistance in different mediums

The resistance in different mediums (fluid or gas) is determined by its decelerating contribution to an object traveling in the certain medium. The resistance is depending on the density of the fluid or gas, the speed of the object, the streamline coefficient and the cross sectional area of the object \[^{55-57}\].

The formula for calculation of a mediums decelerating force on an object traveling in it (at relatively low velocities):

\[
 k_m = \frac{\rho_m \cdot C_D \cdot A}{2} \quad \text{[N]} \quad \text{(eq. 6)}
\]

To calculate the acceleration of an object traveling in a liquid or gas the following formula is used:

\[
 a = g - \frac{\left(k_m - v^2\right)}{m} \quad \text{[m/s}^2\text{]} \quad \text{(eq. 7)}
\]

The different symbols are explained in table 2.1.
Table 2.1 Resistance symbol explanations

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Explanation</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_m$</td>
<td>A mediums decelerating force on an object traveling in the medium.</td>
<td>N</td>
</tr>
<tr>
<td>$\rho_m$</td>
<td>Density of the medium</td>
<td>Kg/m³</td>
</tr>
<tr>
<td>$C_D$</td>
<td>Streamline coefficient, usually estimated or tested</td>
<td></td>
</tr>
<tr>
<td>$A$</td>
<td>Cross sectional area of the traveling object</td>
<td>m²</td>
</tr>
<tr>
<td>$a$</td>
<td>Acceleration</td>
<td>m/s²</td>
</tr>
<tr>
<td>$g$</td>
<td>Gravity acceleration constant</td>
<td>m/s²</td>
</tr>
<tr>
<td>$v$</td>
<td>Velocity of the object, relative to the gas or liquid it is traveling in</td>
<td>m/s</td>
</tr>
<tr>
<td>$m$</td>
<td>Mass of the traveling object</td>
<td>kg</td>
</tr>
</tbody>
</table>

Note that value of $k_m$ must be calculated for each object-fluid combination. Air resistance is often neglected when calculating e.g. velocities due to the low density of air [57].

2.8 Resistivity and conductivity

A materials resistivity is a measure of how much the electron speed are limited because of collisions with atoms in the material and defects in a material. The higher resistivity a material has the lower amount of current can pass through the material. The resistivity depends on material, temperature and the materials geometry.

Conductivity is the opposite of resistivity, with other words a measure of how well a material can transport electrons. Conductivity is generally measured in Siemens /meter [57,58].
3. Methodology

The methodology in this report is explained through description of the choice of method, validity, reliability and critics.

3.1 Choice of method

The choice of method when it comes to a scientific report is always depending on the considered information that one is looking for. A qualitative method is based on the fact that people see different on things and the researcher’s duty is to collect and interpret the information. It is often based on a small group of people and the researcher tries to go a little “deeper” in this group. The result cannot be explained only by numbers but are explained and interpreted in text as words and descriptions. The quantitative method examines statistical quantified results. It assumes that there is an objective reality that is measurable and therefore can be analyzed from tests with numerical results. The researcher has already from the beginning a clear view of what he wants to examine and uses existing theories in his testing and investigations. The results are very specific and often shown in tables, diagrams etc.

A quantitative methodology of research has been used in this report. Information has been found, read and analyzed from books, scientifically reports and interviews with people in different fields of expertise. Calculations have been made out of the test data available from previous tests on the material. The results are shown both in text and in numerical form in tables and diagrams.

3.2 Validity

A report in which materials are compared to each other to find the best suited material for a special application should be validated through several tests of the material. The great variety of materials that exists and the large difference a slight change in the materials structure can have on the properties makes material testing inevitable. Plastic blends are no exception, new blends are developed constantly and many companies have their own blend that is unique due to a different mixture of polymers and additives.

In this report there have not been any tests on the company’s plastic blend instead a more overviewing research of the general materials has been carried
out. Because of the uncertainty of the material blends that could be used for cable protective solutions as in this report the validity of the results should be viewed from that perspective. This is not a final report for a special material blend, it needs to be tested and validated with the specified material. The research that has been made is oriented towards the pursuit of the report but more tests on the exact material have to be executed.

3.3 Reliability

The background material has been taken from various scientifically reports, books and interviews resulting in many different points of view. Since some fields of science within this report are relatively new and still in an experimental stage, it is preferable to base conclusions on both test results and experience. The material blend and possible impurities in recycled plastics as well as environmental conditions such as the temperature has a large effect on the test results and the material should be tested in intended environment for fully reliable values [61].

The people that have been interviewed are all experienced in their respective fields of expertise but they are still human and their knowledge can be based on their own opinion. Proper material tests according to available standards are preferable to get a reliable result. Such tests were not possible to accomplish within the limited time and resources of the project. Suggestions for suitable tests have instead been presented and recommended to ease further testing for more reliable results. Test results from previous tests and data from recognized standards have been analyzed; some calculations have been based on these test results. These results are considered to have good reliability since provable calculations have been used and the tests have been performed according to certain standards.

3.4 Critics

Critics to selected methods are of course lack of some reliable test data on the specific material. More tests should be made to confirm the theory and tests on similar material.
4. Current situation analysis

In this chapter an analysis or mapping of the current situation are done. This analysis is made with a focus on the market, current situation and future possibilities. The recently developed product, Snapp Panzar and its accessories are enlightened here as well as the solution of one other company.

4.1 Offshore cable installations

Today the offshore cable industry is growing rapidly, mostly because of the environmental politics that many countries are pursuing today. Usually there is no reason to stop the production of renewable energy e.g. a wind turbine, if it produces excessive energy, it does not cost anything extra, nor does it affect the environment more. In this case it would be preferable to transport (sell) the excessive renewable energy to another country so that it is not wasted [5,23].

4.1.1 Distant subsea cable connections

The energy industry is continuously evolving and the need to transport energy between countries is always increasing. Some areas in the world are better suited for certain energy sources: Wind energy is naturally harvest more efficient where the winds are strong and steady. Water power plants need cascading waters. Nuclear power plants are preferable placed far from agglomerations. All these parameters together with the difficulties to store electricity, enlightens the increasing need to efficiently transport energy [6,23].

In Sweden there is one project, that is planned to be finished in 2018, to connect the island Gotland to the main land, a distance of roughly 100km. In this project various method are planned to be used, due to the topographic variations that are encountered during installations of this magnitude [7].

4.1.2 Offshore Wind farms

The last few decades the human impact on the environment has been accelerating with the increasing use of energy. Global warming, melting polar ices etc. are topics often discussed among the world leaders and organizations. Development of renewable energy sources is inevitable according to many scientists and reports. The German government announced in 2011 that they are
dismantling all their nuclear power plants to the year 2022, a big part of this will be replaced by renewable energy\textsuperscript{[6,8]}.

One of the most increasing sources of energy is wind power. Today many countries like USA, Germany, England, Sweden and the Netherlands among more have national political wind power programs. The wind turbines have increased massively in size the last years, and with this also increased in efficiency and reliability which makes it more attractive to invest in\textsuperscript{[2,15,63]}.

The best Wind-power sites at land are rapidly being used up, especially in Sweden\textsuperscript{[23]}. This has opened the opportunity to develop wind power at sea (called offshore wind). Figure 4.1 shows a picture from the London array, a huge offshore wind park constructed outside of the UK (opened in 2013).

The offshore wind farms can include a lot of turbines, one park that is planned to be built in Hanöbukten outside Blekinge, Sweden, will consist of 350 to 700 turbines\textsuperscript{[62]}. This many turbines will need to be connected in a secure way with cables and it is desirable to protect the cables with a reliable method. A shutdown of such a park would be very costly due to the amounts of power it constantly produces\textsuperscript{[23, 63]}.

\begin{figure}[h]
\centering
\includegraphics[width=0.8\textwidth]{figure41.png}
\caption{Offshore wind farm – London array\textsuperscript{[20]}}
\end{figure}

These sorts of future plans open up a potentially large market for companies that develop solutions for offshore wind farms and the power grids to connect the plants to each other and also the connections to land\textsuperscript{[10,14]}.
In the 1970s when the oil consumption rapidly increased and the nuclear power plant accidents at Harrisburg and Tjernobyl occurred, the decision makers started to look for other alternatives for energy supply. The solution was obvious to the deciding parties, renewable energy. There are different variants of renewable energy, solar power, bio-fuels, hydropower, wind power etc. [63]

Wind power is one of the areas of research where most amounts of resources are used to meet the demands regarding renewable energy. In the beginning of the 1980s the average commercial wind turbine produced around 25kW, ten years later, the same number was producing 250kW and at the beginning of 2000s the average commercially used wind turbine produced 2500kW [63]. The development of bigger and more power-producing turbines is still ongoing even though it has stagnated the last ten years [5]. Since the size and design of the turbines itself is coming close to an optimum solution, the research today is more focused on stable production and locations for better and more stable winds etc.

The UK government published a report in 2011 regarding their future energy politics, which states that 15% of their energy supply will consist of renewable energy by the year 2020. Of these 15%, the UK estimates that 20% will be generated by offshore wind, meaning approximately 3% or 33-58 TWh of the UK’s total energy production is estimated to be produced by offshore wind by the year 2020. In 2010 around 3 TWh was produced from offshore wind [2].

In July 2013, the worlds, to the date, largest wind farm opened in the UK, named the London Array. This wind farm has a maximum capacity of 630MW, which are enough to provide up to 500.000 homes with electricity [15].

4.1.3 Power grid for offshore wind

Nowitech is a Norwegian research agency within the field of offshore wind technology; in their newsletter from June 2013 they state “Huge savings can be achieved by selecting the best offshore grid configurations” [64]. The same agency has been involved in the power grid installed in the North Sea, between England, Norway, Denmark and the Netherlands. The project’s purpose was to connect all the countries to each other along with several wind farms and single wind turbines at sea.

In the same paper it is stated that cost-effective grid investment and connection is necessary to ensure a coordinated development for the grid and connections.
In the London Array project that was opened in 2013, many companies were involved. A company from Richmond, Pipeline Engineering (CIRCOR Energy) got the contract for the supply of the cable protection system. The price for their services was £7.75 [15] million, approximately 83 million SEK. Included in the price was 6km of their cable protecting system, Peflex, connecting 175 turbines, subsea export cables that will connect the two offshore substations to an onshore substation are also included [21]. A protection of the cables is vital because of the risks of e.g. ships anchor and other may hurt them and this will cause blackouts for many households and industries if it happens at the wrong place [7, 14].

Figure 4.2 show the method Pipeline Engineering uses to connect single turbines to the grid, here it is tested on land. This method is the most common used solution today for this application, due to the difficulties to meet the necessary requirements in another way [12]. A huge advantage with the method, which makes it hard to replace, is the fact that it does not need divers to be installed [15].

![Figure 4.2 Peflex and J-tube testing](image)

In figure 4.2 two products are shown, the J-tube to the left, and the spline-alike cable protection to the right, called Peflex. There are some other companies that develop and manufacture J-tubes and identical solutions, except for some small differences, to Peflex; the only noticeable difference is in the plastic blends,
which are different types of polyurethane for these applications. The disadvantages following polyurethane are the raw material price, and the long manufacturing time. A Swedish company, UW-elast, is active within the field of polyurethane; they state that the price ranges for their different polyurethane blends between 100-500 SEK per kilogram\[22\].

4.1.4 Tekmar Energy Ltd.

A large market for the cable protection industry is the growing wind farm establishments. An example of a well-used solution for this is the one from Tekmar Energy Ltd in UK. They are the world leading company when it comes to offshore cable protection and a presentation of the company and their solution is described here as an example of the current.\[65\]

4.1.4.1 Company history

Tekmar was founded 1985 in Norway as a response to the increasing demands of high technology solutions for the subsea industry including gas- and oil industry. Several “diver-less” products was developed for deep-water operations as robotic pipeline repair systems. In 1995 Tekmar relocates to northern England to benefit from the shipbuilding industry and their experience. Tekmar energy was formed in 2007 as a new part of the company with focus on the renewable energy industry and their need for protection systems of cables. From this point forward investment has been made to further develop this part of the company. Tekmar energy is now the primary supplier of cable protection system to the offshore wind farm industry with revenue of 22 million £ in 2012 and 75 in their staff.\[65\]

4.1.4.2 Product

Tekmar energy has developed their “Teklink cable protection systems” as a complete solution which is protecting the cable all the way from the seabed up and into the wind turbine. The product is made of polyurethane material TEKTHANE® and is well suited for the harsh environments the product is exposed to.

The installation is done without any divers and this is of course a great advantage for the product. Figure 4.3 shows the cable protection system with locking devices for fastening into the wind turbine. The pipe is connected to the cable on the seabed and both are dragged into the wind turbine and attach to e.g. a J-tube as in figure 4.2.\[65\]
4.2 Snapp Panzar

Snapp found out that their land-pipes where occasionally being used as cable protection when laying offshore cable. This lead to the development of Snapp Panzar, a cable protective pipe especially designed for underwater environment and installation. It consists of one upper half, one lower half and three locks \[12\]. Snapp Panzar is illustrated in figure 4.4. The main difference with Snapp Panzar is the increased wall thickness from 6mm to 10mm and reinforcements around vital parts. Pictures of the molds for the pipes are shown in Appendix 3.
4.2.1 Snapp Panzar material

The Material Snapp Panzar consist of is a polymeric binary compound (blend). One part will be Polypropylene (PP) and the other; Ethylene propylene diene monomer (EPDM). The amounts of each part are yet to be determined. When the mold arrives, tests will be made to ensure what amount of the elastomer that is needed to obtain satisfactory impact strength. Snapp Panzar will contain the additive CB for increased UV-resistance and surface strength.

Snapp Panzar will almost exclusively be manufactured by mechanical recycled plastics [12].

4.2.2 Functions

Snapp Panzar has numerous functions, to help transports, installations and maintenance work. The pipe is manufactured in two separate halves, partly to favor the injection molding process and partly to provide the possibility if needed during installation or maintenance.

Another function is that the locks have three different positions, in figure 4.5 it can be seen what each position for the locks are planned to be used for [12].

Figure 4.5 Lock positions

1. Open position, while the locks are in this position, the pipe can be opened and closed unhindered.
2. Transport position, meant for the transportation so the locks can be attached to the pipe and still it is able to remove them by hand.
3. Final locked position; this is the final position that will hold the pipe locked on the seabed for decades. Tools are needed to remove the locks.

Additional functions are; circulation holes (gills), feets for better transport and handling and universal holes on both sides. The universal holes can be useful in various situations, but their main task is to provide additional fastening points if needed [12].
4.2.3 Locks

The locks are the only part that is not made out of recycled material. They need certain rigidity and will instead be manufactured by acetal (polyoxymethylene, POM). It is important that they are kept intact and not get worn down and eventually unlocks the pipe \(^{[12]}\). The locks are illustrated in figure 4.6.

![Locks Image]

Figure 4.6 Lock

4.3 Sea Weight

One problem with using plastic pipes instead of concrete or cast iron is that the plastic has approximately the same density as water, and therefore it is no certainty that they sink. This can be solved with the use of weights of various kinds which affect the total cost and possibly the life length \(^{[12]}\).

4.3.1 Existing solutions

One solution is to use weights that have been design for this purpose, a company in Henkelstorp, Sweden called H.S.G. manufacture weights like these. The weight H.S.G make are adapted for plastic pipes with smooth surface to prevent surface scratching of the plastic. H.S.G manufactures three different types of weights today, in different sizes. The weights are fastened with belts, similar to the safety belt in a standard car \(^{[67]}\).
4.3.1.1 Mini-weight

A streamlined weight with smooth surface made for the smallest pipe-dimensions. The weight can be adjusted between 2-6 kilograms and the maximum diameter for the pipe is 90mm. In figure 4.7 the mini-weight is shown [67].

Figure 4.7 Mini-weights [67]

4.3.1.2 Tube-weight

The tube-weight is shaped like a long pipe; it is a type of plastic tube filled with concrete. The tube is attached in both ends to the cable protective pipes. This weight is used when the mass of the weight needs to be more uniformly distributed along the pipes. This weight is often used when the circumstances are rough. The weight can be adjusted between 6-40 kilograms and the maximum diameter for the pipe is 160mm. In figure 4.8 the tube-weight is shown [67].

Figure 4.8 Tube-weight [67]
4.3.1.3 U-weight

The U-weight is used when high weight is needed, and for pipes of the largest diameters. It is similar to the Mini-weight but larger and attached with two belts instead of one. This weight is not of a streamlined shape. The weight is also shaped with two notches in the bottom to make it possible to use a forklift to lift the weights. The mass can be adjusted between 15-2000 kilograms and can be made for any diameter above 110mm. In figure 4.8 the U-weight is shown [67].

Figure 4.9 Attached weights [67]

4.4 Field investigations

To obtain opinions from all levels in the industry for cable installation, several field trips and interviews with people active within the field was carried out. The events that took place during the project were:

- Study trip to “Plastteknik Nordic” (Appendix 4)
- Interview with Jan Lillieblad at A-betong (Appendix 5)
- Interview with Fredrik Molander at Meag VA-system (Appendix 5)
- Interview with Lars Pettersson’s diving team (Appendix 6)
- Two Interviews with Gunnar Gehlin at Svenska kraftnät (Appendix 7)
- Continuous interview with Leif Pettersson (Appendix 8)
5. Implementation

This chapter explains how this project has been carried out. Different methods have been used to come up with the results and a short description of each step is explained.

5.1 Literature study

A substantial part of the project has been a pure and simple literature study. Several scientific reports have been read and analyzed and connections have been made to the applications. The kind of information needed for the project was clear from the beginning and the work has consisted of finding articles connected to our investigations. Comparisons between different studies have been made and a summary of different results in the studies has been assembled.

5.2 Test analysis

Tests have been made on many products made of different materials around the world and results from tests are shown in several reports and articles. Data have been gathered and analyzed from tests and used as a source in the comparison of pipe sustainability and usability.

5.2.1 Snapp pipes

Tests on Snapp´s pipes have earlier been executed by the Company Snapp together with SP – Technical research institute of Sweden. Data from these tests have been analyzed in this report and strength properties for the pipes have been derived. Calculations have been made from these values to investigate the pipes ability to restrain different situations.

5.2.1 Similar materials and applications

Tests on materials and constructions similar to Snapp´s pipe have been evaluated in the report. Test results both for concrete and cast iron has been analyzed as well as tests on additives in plastic blends. Tests including life length, protective coatings and environmental impact have been analyzed for the different materials.
5.3 Current situation analysis

To fully understand the current situation, which is important on the subject, a chapter has been dedicated to analyze it. Several examples of solutions for cable protection have been highlighted. Also the different applications that are relevant for protection pipes like Snapp’s have been presented. A field investigation was carried out to complement the very theoretical study.

5.3.1 Field Investigations

This field investigation includes several interviews, a trip to a plastic fair and a visit of the manufacturing of Snapp’s products.

5.3.1.1 Interviews

An important part of the project has been to interview professionals within the regarded fields to get experienced opinions according the different areas of investigations. Interview with Gunnar Gehlin at Svenska kraftnät has been made to understand how the cable protection and cable laying procedure is made.

Interviews with people in the concrete manufacturing business have been made to get their opinion of how well concrete pipes manage in a submarine environment in a long term perspective. Conversations with divers that work with installations of underwater pipes at a daily basis have been important. This gives the report a view from people close to the installation process.

A continuous contact has been held with Leif Pettersson who has taken the role as a mentor regarding knowledge that concern plastics.

5.3.1.2 Fair visit

Since the writers of this report had little experience from the plastic industry, study visits was made to expand the knowledge level in the field. A summary of the visit to Plastteknik Nordic, a plastic fair in Malmö, can be found in Appendix 4. It also includes a short description of the companies we talked to and found interesting.
6. Results

Here the results from the research study are presented, divided in Lifetime and reliability further on an environmental impact between the different materials. At last an investigation of Snapp Panzar compatibility, including strength calculations and complements.

6.1 Lifetime and Reliability

Lifetime predictions are a very important issue when it comes to protection of subsea cables. The cables have an expected life length that stretches far into the future. The cables are expected to last at least 40 years and a life length even up to 100 years is not impossible according to Gehlin \cite{18}. A decision on type of material to be used in cable protection should of course be well supported by a worked through investigation.

6.1.1 Ageing test- polypropylene pipes

There is today no international accepted method for evaluation of the material durability of non-pressure pipes. Pipes are chosen after experiences from professionals and comparisons between earlier installations. It is a well-known fact that plastic pipes are well suited for underwater environments due to their corrosion resistance and flexibility to ground movements \cite{61}. Since so many plastic materials exist with different compounds and the environmental factor is of such large importance test should be adapted for the right compound in the right environment \cite{54}.

6.1.1.1 Life time test

SP Technical Research Institute of Sweden has tested non-pressure pipes with a polypropylene mixture (PP) very similar to the one Snapp uses in their pipes. The results are evaluated after ageing at 95°C according to Standards \cite{68}. Focus is here is on the “degradation of thermal ageing”. The test specimen is placed in a tank with water for 12 months. \cite{61}. Test methods are shown in table 6.1
Table 6.1 Property and methods in testing procedure[61]

<table>
<thead>
<tr>
<th>Property</th>
<th>Material age</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degradation from thermal ageing</td>
<td>Virgin and aged (selected temperature and time)</td>
<td>Mechanical properties before and after ageing and resistance to thermo-oxidative degradation</td>
</tr>
</tbody>
</table>

6.1.1.2 Results

Lifetime prediction according to Arrhenius equations (eq. 1) are used to get a result from the test. The material is a commercial polypropylene polymer, and its properties are shown in table 6.2. It is commonly used in Europe for among many other things cable protection and is because of this well suited as a test specimen in this report[61].

Table 6.2 Material properties for tested material

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>Specimen value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt flow rate [g/10 min]</td>
<td>0.3</td>
</tr>
<tr>
<td>Density [g/cm³]</td>
<td>0.9</td>
</tr>
<tr>
<td>Modulus of elasticity [MPa]</td>
<td>1500</td>
</tr>
<tr>
<td>Yield stress [MPa]</td>
<td>30</td>
</tr>
<tr>
<td>Notched impact strength [kJ/m²]</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>+23°C</td>
</tr>
<tr>
<td></td>
<td>− 20°C</td>
</tr>
</tbody>
</table>

The results for lifetime prediction are shown in table 6.3. What one can notice is that it is a remarkable difference in lifetime from 20°C up to 40°C. The lifetime is therefore proven to be very temperature dependent. Another thing is that the lifetime is strongly improved with a lowered temperature.
Table 6.3 Results from life time tests [61]

<table>
<thead>
<tr>
<th>Test material</th>
<th>Lifetime prediction. 40°C</th>
<th>Lifetime prediction. 20°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>340 years</td>
<td>3400 years</td>
</tr>
</tbody>
</table>

There is shown a minor deterioration of the material properties after 12 months in this test. The material handles ageing well even in a long term perspective. The ring stiffness is slightly impaired due to an increase in the modulus which makes the material more ductile. The ability to withstand tensile stress shows minor changes after ageing procedure compared to before [61].

6.1.1.3 Carbon Black – possible galvanic corrosion

The amount of CB used in the blend controls how much the electrical properties are affected, logically; the interesting part is the huge difference between 3 and 4 wt. % CB in the blend. In figure 6.1 the results for the two different PP/EPDM-blends are shown for varied amount of CB (1-6 wt. %).

Figure 6.1 Volume resistivity in blends due to CB [31]
As seen in figure 6.1 the electrical volume resistivity start to deteriorate when the amount of CB goes from 3 to 4 wt. %, especially for the dynamically vulcanized (TPV) polymer blend. The volume resistivity is reduced from around a value of $10^{15}$ to as low as $10^4$ for TPV ($10^{16}$ to $10^8$ for TPE) [31].

The electric volume resistivity is the inverse of the electric conductivity which is one of the basic prerequisites to galvanic corrosion [69,70].

According to a report conducted in 2007 there is shown some electrochemical activity with an increased amount of carbon black in polymers [69], and in a study of earlier non-conductive composites mixed with carbon substances galvanic corrosion appears [70]. This shows the increased possibility of galvanic corrosion when adding carbon black into plastic with an increased conductivity as a result.

### 6.1.2 Lifetime - Concrete

The corrosion in concrete is driven only by biological processes as long as the concrete isn’t damaged in a way that makes the reinforcements lay uncovered [71]. One issue is that concrete seems to act very different in seawater in different situations. Wakeman [72] asked already in 1958 “Why do some concrete structures seem to last indefinitely in seawater while others deteriorate within a comparatively short time?” This question has still no exact answer; of course theories exist like, a low cement/water ratio could be the cause but an exact answer remains hard to achieve [73].

The life length depends on the rate of chloride ions ingress in the reinforced concrete material. [74]

The corrosion of the reinforcement starts when chlorides from e.g. seawater penetrate the concrete and reaches the reinforcement [73]. Several observations show that the corrosion starts where there is a local air pocket or pores that makes oxygen pierce into the reinforcing steel and initiate the corrosion phase.

The risks for material failure are almost exclusively connected to the corrosion of the reinforcements in the concrete e.g. steel. One recent study show the decreased strength and reliability of concrete members when the reinforcing steel is exhibited to corrosion and expanding in volume. In figure 6.2 the crack propagation in the concrete can be seen when the reinforcements within corrode.
The results of the study were mainly that when the reinforcing metal corroded and expanded, stresses in the concrete emerged, which counteracted the expansion of the rust. The encapsulated stresses resulted in the entire concrete member being more brittle and therefore less resistant to any kind of impact or scratching \cite{75}.

6.1.3 Lifetime - cast iron

Bacteria has long been known as a potential factor in the corrosion processes of different metals including cast iron but it has not been connected with the amount of corrosion loss and pit depth together with the environmental conditions and exposure time. The microbiological activity is shown to be an important factor in the short- and long term corrosion of cast iron in a marine environment such as the seabed. In his thesis R.E Melcher \cite{38} divides the corrosion into 4 important phases with a combination of bacterial processes and an oxidation process that makes the material corrode. The model is one of its kind because of account is taken to the fact that the corrosion process changes over time \cite{38}. 

\begin{figure}[h]
\centering
\includegraphics[width=0.7\textwidth]{figure6.2}
\caption{Reinforced concrete cylinders, rusted\cite{75}}
\end{figure}
Figure 6.3 shows the different phases in the model and already before phase 1 an important matter with respect to start of corrosion takes place. When material is immersed into saltwater or protected material losses cover and is exposed in the medium, bacteria and other organisms are attached to it and depending on the nutrient level it may affect an early corrosion of the material.

In phase 1 and 2 traditional electrochemical processes (galvanic corrosion) takes place. Corrosion products are built up and stops the oxygen from reaching the surface of the material and anaerobic conditions develops. In phase 3, sulphate-reducing bacteria flourish in the conditions that now exist; the corrosion rate depends of the amount of bacterial metabolism and the access to nutrients. The last phase is explained as almost linear where the corrosion rate still depends of the nutrient supply to the bacteria.

Figure 6.4 shows the effect of nutrient level in the water where a difference can be seen between water with high nutrient level and a low level of nutrient. The test specimen in an environment with high nutrient level has a clearly higher corrosion rate\textsuperscript{[38]}. 
According to R.E Melcher\cite{74} two things matters most when it comes to corrosion in infrastructural installations, corrosion loss and pit depths. In figure 6.5 it’s clear that pitting corrosion is affected much from anaerobic bacteria in phase 3 and 4 (phase 3 starts right before one year).

The corrosion clearly does not stop because oxygen supply ends.\cite{38} And another thing that has been held as an important factor for corrosion is the salinity that has been shown in some cases\cite{76} not to have any particularly effect on the long-term corrosion losses.\cite{77} While in other reports it has occasionally been a vital part \cite{78}. 

---

Figure 6.4 Example of the effect of nutrient load on corrosion loss at two otherwise identical sites\cite{38}
6.1.3.1 Corrosion rate

Despite the fact that corrosion varies very much from different locations and environments results from different tests can be found for example from Melcher.\cite{79}. In table 6.4 is yearly corrosion in different environments shown. From figure 6.4 a corrosion rate of around 0.3 mm/year can be seen the first 1.5 year and in figure 6.5 general corrosion of 1 mm in 2.5 years and pit corrosion of 2 mm in the same time is shown.

Table 6.4 Estimated long time corrosion rates (mm/year)

<table>
<thead>
<tr>
<th>Exposure condition</th>
<th>Fresh water</th>
<th>Seawater Immersion</th>
<th>Tidal</th>
<th>Atmosphere Coastal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey cast iron</td>
<td>0.03</td>
<td>0.1</td>
<td>0.1</td>
<td>0.007</td>
</tr>
</tbody>
</table>
6.2 Environmental impact

Here the environmental impact is investigated, summations of test results are made and focus has been on CO₂ emissions and possibilities for recycling.

6.2.1 Plastics (polypropylene)

When recycling plastics, huge savings on the environment can be made, the exploration of natural gas and oil can be reduced significantly. When recycling plastics, the manufacturing process of polymer and the oil extraction process is avoided, this is approximately 95% of the total energy consumption during the manufacturing process. It should not be forgotten that the recycling process requires energy, and if the mechanical properties are of vital importance, glass fibers or similar additives must be added during the recycling process [80].

A study that carried out in Sweden showed that the mechanical properties of polypropylene are slightly affected when recycling, in a recent test study a test specimen of polypropylene was recycled 14 times and remolded and tested between each recycling. The test included tensile strength, young modulus and melt flow index. The tensile strength and the young modulus was reduced in value slightly, 9.3% respectively 13.7%. Melt flow index increased with a value of more than double after 14 recycling runs [80]. Another report present similar results, an increasing MFI, a slightly reduced tensile strength. In the report it was also examined how the impact strength are affected by recycling. The test specimens where recycled 10 times and tests performed after each recycle, showing that impact strength remained without noticeable changes by the recycling processes [81].

In a scientific report regarding the subject, published by the Department of Environmental Engineering, Technical University of Denmark, it is stated that the changes in the mechanical properties of the material mostly depend on the purity of the recycled plastics. Additives and impurities are factors that can affect the recycled plastics properties. In the same report it is investigated what environmental advantages recycled HDPE have over virgin HDPE (HDPE and PP are considered equal in this situation due to their equal Carbon content [82, 83]). In table 6.5 the results are shown.
Table 6.5 Environmental comparison recycled/virgin HDPE [82]

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Reprocessing of $10^3$ kg HDPE to granulate</th>
<th>Production of $10^3$ kg virgin HDPE to granulate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>kWh</td>
<td>330</td>
<td>681</td>
</tr>
<tr>
<td>Natural Gas (fuel)</td>
<td>Nm³</td>
<td>24</td>
<td>136</td>
</tr>
<tr>
<td>Natural gas (feedstock)</td>
<td>Nm³</td>
<td>0</td>
<td>565</td>
</tr>
<tr>
<td>Oil (fuel)</td>
<td>L</td>
<td>0.6</td>
<td>214</td>
</tr>
<tr>
<td>Oil (feedstock)</td>
<td>L</td>
<td>0</td>
<td>928</td>
</tr>
</tbody>
</table>

When converting the electricity and fuel values to CO₂ –emissions, it can be observed that savings of 1082 to 1626 kg CO₂-eq. / $10^3$ kg are made each time the HDPE are recycled [82], additional environmental savings are made by preventing the use of natural gas and oil as feedstock. The variety is due to the difference in CO₂ –emissions for the electricity provision method.

Similar values were published in a report in 2013. They report that reductions of 450 to 1830 kg CO₂-eq. / $10^3$ can be made in the manufacturing process (excluding feedstock values) by using recycled, instead of using virgin Polypropylene [83].

6.2.2 Concrete

Concrete is one material that has low CO₂ –emissions /kg material produced. Approximately 5% of the world’s CO₂ -emission originate from the manufacturing of cement, which are the binder used in concrete. Producing 1kg of cement result in 0.66 - 0.82kg CO₂ emission, the value varies due to the energy source. To manufacture OPC, Ordinary Portland Cement, the worldwide most commonly used cement, heating of raw materials to temperatures around 1400 degrees Celsius is made. This heating is the main contributor to the energy need during manufacturing of the OPC [84,85].
When making concrete, the cement is mixed with water and aggregates. In a study it was investigated how much CO$_2$ was emitted when 1m$^3$ of concrete was manufactured, transported and constructed. The result was 354kg CO$_2$ emissions, off which 269 kg CO$_2$ was emitted from the manufacturing of the OPC (328kg OPC used) [84].

6.2.3 Cast iron

The iron and steel industry is the sector that consumes the most energy in the world (2009). The amount of CO$_2$/kg iron produced varies due to the manufacturing method. The basic rule is that CO$_2$ emissions decrease as the manufacturing cost increase, and vice versa. In figure 6.6 it is shown an estimation of the correlation between manufacturing costs and direct CO$_2$ emissions [86].

![Figure 6.6 direct kg CO$_2$ emission/kg steel - Cost (steel production)](image)

Figure 6.6 shows how the costs increase more rapidly when the CO$_2$ emissions are approaching the 1:1 relation. These values are the direct CO$_2$ emissions, not counting the emission connect to electricity, transport, construction etc. There are large investments in developing more environmental methods to manufacture iron and steel, the total CO$_2$ emissions depend on the manufacturer, and often varies from 1-2 kg CO$_2$/kg iron produced (life cycle CO$_2$ emissions). The same applies to the costs in figure 6.6, only the raw material and energy costs are considered [86,87].

Pangang Group Research institute in China recently (2012) [87] performed an investigation regarding the total CO$_2$ emissions when producing 1 tonne of Panzhihua steel. Panzhihua steel is a common kind of steel in china, produced in the region, Panzhihua. The result was 1427.3kg CO$_2$/10$^3$kg pig iron [87].
6.2.4 Life cycle analysis

A study of a LCA – Life cycle analysis comparing materials for water transporting pipes recently carried out. The test compared amount of CO$_2$ emitted for 1km of pipe manufactured transported and installed for pipes made of cast iron, ductile iron, concrete, reinforced concrete and HDPE. The test showed that the use of concrete result in less CO$_2$ emitted than both cast iron- and HDPE pipes [88], the results are illustrated in table 6.6.

Table 6.6 Total CO$_2$ emitted during life cycle of 30.5cm (inner diameter) pipe [10$^3$ kg CO$_2$/km] [88]

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Total CO$_2$ – emission</th>
<th>Production phase</th>
<th>Installation phase</th>
<th>Transportation phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>68.3</td>
<td>63.1</td>
<td>2.91</td>
<td>2.26</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>152</td>
<td>146</td>
<td>2.91</td>
<td>2.47</td>
</tr>
<tr>
<td>Ductile Iron</td>
<td>472</td>
<td>468</td>
<td>3.28</td>
<td>0.88</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>353</td>
<td>349</td>
<td>3.28</td>
<td>0.84</td>
</tr>
<tr>
<td>HDPE</td>
<td>218</td>
<td>215</td>
<td>2.81</td>
<td>0.17</td>
</tr>
</tbody>
</table>

The mass and the wall thicknesses of the materials could vary, the important aspect where that they were leak-proof. It should be observed that the CO$_2$ values are not correlated with material mass but the length of 1 km pipe.

6.3 Snapp Panzar analysis

Snapp Panzar is a groundbreaking product in many aspects, with many possible fields of application due to the many universal solutions in the design. Here it is clarified what loads and impacts that Snapp Panzar can withstand during installations.

Snapp Panzar 160 have not yet been tested, but the company’s other pipes for land-application have been tested, both for tensile- and impact strength. The land-pipes are of less thickness than Snapp Panzar, wall thickness of the land-pipe is 6mm, while Snapp Panzar has a wall thickness of 10mm. This provides an extra safety factor not shown in these results.
6.3.1 Pipe Strength

Together with SP – Technical research institute, Snapp has made tests on their pipes for a classification according to SPF standard 5200[31]. Two different kinds of tests have been performed, one for impact strength and one for ring stiffness. These two properties can be adjusted by the amount of EPDM in the blend.

6.3.1.1 Effects of EPDM

A test that carried out in Mumbai, India showed that the amount of EPDM in the blend conform well to the type of failure in the material when the different test-sheets (pieces of 12x12 cm of the different blends) were loaded to breakage. In a PP/EP-blend (1:1) when the amount of EPDM varied between 0-75 wt. % the results seen in table 6.7 showed[89].

<table>
<thead>
<tr>
<th>EPDM wt.%</th>
<th>Type of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-10</td>
<td>Brittle</td>
</tr>
<tr>
<td>20-50</td>
<td>Thermoplastic</td>
</tr>
<tr>
<td>75</td>
<td>Elastomeric</td>
</tr>
</tbody>
</table>

The failure type is well connected to impact / tensile strength of the material. A brittle failure generally means low impact strength but higher tensile strength. Elastomeric failure generally means high impact strength but lower tensile strength [31, 89].

6.3.1.2 Results Ring stiffness test

A summary of the tests for ring stiffness is shown in table 6.7 and the full test results are found in Appendix 9. The test is conducted according to standards (see theory part 2.5.1, classification of pipes) with a deflection of 5% of total diameter as the limit to reach the classification approval.
Table 6.7 Ring stiffness test result

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test number</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer diameter [mm]</td>
<td></td>
<td>110</td>
<td>160</td>
<td>160</td>
<td>160</td>
<td>60</td>
</tr>
<tr>
<td>Force [N]</td>
<td></td>
<td>704</td>
<td>850</td>
<td>850</td>
<td>810</td>
<td>770</td>
</tr>
<tr>
<td>Deflection</td>
<td></td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>% of deflection</td>
<td></td>
<td>4,5</td>
<td>4,4</td>
<td>4,4</td>
<td>4,4</td>
<td>5,2</td>
</tr>
</tbody>
</table>

From these results we can easily see the amount of load that the pipes can handle before deflect more than 5% of total diameter. We calculate with a force of 800 N because the fact that the pipes used for offshore applications is at least 160 mm in outer diameter and the results depend on the diameter of the pipe. Also as mentioned before, the material thickness of the offshore pipes are thicker than the tested pipes. We use equation 3 to calculate the load limit of the pipes.

\[
m = \frac{F}{a} = \frac{F}{g} = \frac{800N}{9.81} \approx 81.5 \text{ kg}
\]

This gives us an allowable load limit of 81.5 kg pressure on the pipes before an elongation of more than 5% are expected.

6.3.1.3 Results impact strength test

The test for impact strength was also conducted by SP – Technical research institute of Sweden, and is approved for SRS class [51]. This gives us the possibility to calculate impact strength in certain application for our pipes such as when a pipe is covered with rocks to protect the cable even more. Symbols in calculations are explained in table 6.8.
To compare this test with the situation of the crushed rocks falling on the pipe, the following assumptions have been made:

1. The hitting area, in which the impact force is distributed are the same in the two situations.
2. The air resistance is neglected in the test.
3. The streamline coefficient of the rocks, $C_D = 0.5$
4. The rocks are shaped cubical.
5. Rocks grain density $\rho_{rock} = 3000$ [kg/m$^3$] (normally $\rho_{rock} = 2200 - 2700$ [kg/m$^3$])
6. Water density $\rho_{H,O} = 1000$ [kg/m$^3$]
7. Since the depth of the specific situation is varying, it is assumed that the rocks reach their maximum speed in water; meaning the acceleration from gravity and deceleration (negative acceleration) from the water resistance are equal.

### Table 6.8 Snapp Panzar subsea impact strength

<table>
<thead>
<tr>
<th>Designation</th>
<th>Explanation</th>
<th>Value</th>
<th>Unit</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_{spear}$</td>
<td>The speed of the spear at impact</td>
<td></td>
<td>m/s</td>
<td>Calculated</td>
</tr>
<tr>
<td>$v_{0,spear}$</td>
<td>The ingoing speed of the spear</td>
<td>0</td>
<td>m/s</td>
<td>Given</td>
</tr>
<tr>
<td>$a_{spear}$</td>
<td>The acceleration of the spear</td>
<td>9.81</td>
<td>m/s$^2$</td>
<td>Same as $g$ determined</td>
</tr>
<tr>
<td>$g$</td>
<td>gravitational acceleration constant</td>
<td>9.81</td>
<td>m/s$^2$</td>
<td>Given</td>
</tr>
<tr>
<td>$h_{spear}$</td>
<td>The falling distance for the spear</td>
<td>1</td>
<td>m</td>
<td>Given</td>
</tr>
<tr>
<td>$m_{spear}$</td>
<td>The mass of the spear</td>
<td>10</td>
<td>kg</td>
<td>Given</td>
</tr>
<tr>
<td>$p_{spear}$</td>
<td>The translational momentum of the spear</td>
<td></td>
<td>kg · m/s</td>
<td>Calculated</td>
</tr>
</tbody>
</table>
Continuation of Table 6.8 Snapp Panzar subsea impact strength

<table>
<thead>
<tr>
<th>Designation</th>
<th>Explanation</th>
<th>Value</th>
<th>Unit</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p_{\text{allowed}} )</td>
<td>The allowed translational momentum of the rocks</td>
<td>44.3</td>
<td>kg \cdot m/s</td>
<td>Same as ( p_{\text{spear}} ) determined</td>
</tr>
<tr>
<td>( k_{\text{H}_2\text{O}} )</td>
<td>Acceleration resistance of the water</td>
<td></td>
<td>m/s²</td>
<td>Relative calculated</td>
</tr>
<tr>
<td>( \rho_{\text{H}_2\text{O}} )</td>
<td>The density of the water</td>
<td>1000</td>
<td>kg/m³</td>
<td>Given</td>
</tr>
<tr>
<td>( C_D )</td>
<td>Streamline constant</td>
<td>0.5</td>
<td></td>
<td>Assumed</td>
</tr>
<tr>
<td>( A_{\text{rock}} )</td>
<td>Specific cross section area of the rocks</td>
<td></td>
<td>mm²/10⁶mm³</td>
<td>Calculated</td>
</tr>
<tr>
<td>( a_{\text{rock}} )</td>
<td>The acceleration of the rocks</td>
<td>0</td>
<td>m/s²</td>
<td>Determined</td>
</tr>
<tr>
<td>( v_{\text{rock}} )</td>
<td>The velocity of the rocks when acceleration stops</td>
<td></td>
<td>m/s</td>
<td>Calculated</td>
</tr>
<tr>
<td>( m_{\text{rock}} )</td>
<td>The maximum allowed mass of the rock</td>
<td></td>
<td>kg</td>
<td>Calculated</td>
</tr>
<tr>
<td>( \rho_{\text{rock}} )</td>
<td>The grain density of the rocks</td>
<td>3000</td>
<td>kg/m³</td>
<td>Estimated</td>
</tr>
<tr>
<td>( V_{\text{rock}} )</td>
<td>Specific volume of the rocks</td>
<td>0.001</td>
<td>m³/3kg</td>
<td>Determined</td>
</tr>
<tr>
<td>( V_{\text{rock, max}} )</td>
<td>The maximum allowed volume of the rocks</td>
<td></td>
<td>dm³</td>
<td>Calculated</td>
</tr>
</tbody>
</table>
6.3.1.3.1 Calculations

The hitting area is assumed to be the same in the two situations, (the spear in the test and the stone in the application) therefore only the translational momentum is relevant. The momentum of the “spear” that hit the pipe in the impact test is calculated to start with, using equation 4 and 5.

\[
a_{spear} = g = 9.81 \, [\text{m/s}^2]
\]

\[
v_{spear}^2 - v_{0,spear}^2 = 2 \cdot a_{spear} \cdot h_{spear} \Rightarrow
\]

\[
\Rightarrow v_{spear} = \sqrt{2 \cdot a_{spear} \cdot h_{spear}} = \sqrt{2 \cdot 9.81 \cdot 1} \, [\text{m/s}^2]
\]

\[
v_{spear} = 4.43 \, [\text{m/s}^2]
\]

\[
p_{spear} = v_{spear} \cdot m_{spear} \Rightarrow p_{spear} = 4.43 \cdot 10 \, [\text{kg} \cdot \text{m/s}]
\]

\[
p_{spear} = 44.3 \, [\text{kg} \cdot \text{m/s}]
\]

This can be considered as the momentum that the pipe can withstand. The next step is to calculate the translational momentum of the crushed rocks, since the sizes of the rocks can be different; the goal of the calculations will be to find the maximum size of the rocks.

It was assumed that the rocks reach their maximum velocity in water, when the acceleration cease. Earlier the air resistance was neglected, because the influence on the result would have been minimal. The water resistance affects the result more, therefore it must be considered. At relative low velocities eq. 6 can be used.

\[
k_{H_2O} = \frac{\rho_{H_2O} \cdot C_D \cdot A_{rock}}{2} \, [\text{N}]
\]
A projection was made in Solid Works to see the cross section area of the assumed cubic rock falling with one corner straight down to get maximum area and lowest stream line coefficient. This gives us a relation between volume and cross sectional area.

\[ A_{rock} = 17320.5 \text{ [mm}^2 / 10^6 \text{ mm}^3] \]

By using this area/volume relation together with the assumed grain density for the rocks, a relation between cross sectional area and mass are determined as following

\[ A_{rock} = \frac{17320.5 \cdot 10^{-6}}{\rho_{rock} \cdot V_{rock}} \cdot m_{rock} = \frac{17320.5 \cdot 10^{-6}}{3000 \cdot 0.001} \cdot m_{rock} \text{ [mm}^2] \]

\[ A_{rock} = 5773.5 \cdot 10^{-6} \cdot m_{rock} \text{ [mm}^2] \]

By using this relationship in equation 6 we get a new relationship (equation 8), between the decelerating force and the mass.

\[ k_{H_2O} = \frac{1000 \cdot 0.5 \cdot 5773.5 \cdot 10^{-6} \cdot m_{rock}}{2} \Rightarrow k_{H_2O} = 1.443375 \cdot m_{rock} \text{ [N]} \quad \text{(eq. 8)} \]

To find out the maximum velocity of the rocks in water that is when the positive acceleration from gravity and the negative acceleration from the water resistance are equal. The acceleration of the rocks at maximum velocity is set to:

\[ a_{rock} = 0 \text{ [m/s}^2]. \]

The formula for the resulting acceleration when the maximum velocity is reached is seen in equation 9.

\[ a_{rock} = g - \frac{(k_{H_2O} - v_{rock}^2)}{m_{rock}} = 0 \text{ [m/s}^2] \quad \text{(eq. 9)} \]
By rewriting equation 4 and using the value for allowed translational energy, a value for maximum velocity depending on the mass are obtained in equation 10.

\[ P_{\text{allowed}} = p_{\text{spear}} = v_{\text{rock}} \cdot m_{\text{rock}} \Rightarrow v_{\text{rock}} = \frac{44.3}{m_{\text{rock}}} \text{ [m/s]} \quad \text{(eq. 10)} \]

Calculated relations from equation 10 and equation 8 in equation 9 gives:

\[ g = \frac{1.443375 \cdot m_{\text{rock}} - \left( \frac{44.3}{m_{\text{rock}}} \right)^2}{m_{\text{rock}}} = \frac{1.443375 - \frac{44.3^2}{m_{\text{rock}}^3}}{1} \text{ [m/s}^2] \]

A value for the gravitational constant depending on mass is obtained. The gravitational constant is \( g = 9.81 \).

\[ 9.81 = 1.443375 - \frac{1962.5}{m_{\text{rock}}^3} \]

From this, the allowable mass for the rocks due to impact is calculated.

\[ \frac{1962.5}{m_{\text{rock}}^3} = 1.443375 - 9.81 \Rightarrow m_{\text{rock}} = \sqrt[3]{\frac{1962.5}{8.366625}} = 6.167177... \approx 6.2 \text{ [kg]} \]
With the result for maximum allowed mass, the allowed volume and the maximum velocity is determined.

\[
v_{\text{rock, max}} = \frac{44.3}{6.2} \approx 7.2 \text{ m/s}
\]

\[
V_{\text{rock, max}} = \frac{m_{\text{rock}}}{\rho_{\text{rock}}} = \frac{6.2}{3000} = 0.0020566\ldots \approx 2.1 \text{ [dm}^3]\]

**Results:**

The maximum velocity of the rocks is:

\[
v_{\text{rock}} = 7.2 \text{ [m/s]}
\]

The allowed mass for the rocks are:

\[
m_{\text{rock}} = 6.2 \text{ [kg]}
\]

The allowed volume for the rocks, with the assumed density, is:

\[
V_{\text{rock, max}} = 2.1 \text{ [dm}^3]\]
6.3.2 Complements

To increase the field of use for the product, some complements for Snapp Panzar are preferable. This chapter describes our solution for a sea weight.

In similar projects where plastic pipes have been used approximately 1 weight per 6 meter has been used. This means that only 1/6 of the price of the weight will be added to the 1 meter long pipes that Snapp produce.

6.3.2.1 Concept

The idea is to make the weight in plastics as well, hollow and then fill it with concrete, iron etc. The concept is to create three new molds to make a bottom piece mold, a top piece mold and one middle piece mold. This is made so the number of middle pieces used for the certain situation can be adjusted. Sometimes more weight is needed, sometimes more volume is needed. In figure 6.7 a rough sketch of the concept of the current idea of Snapp is illustrated.

![Figure 6.7 Rough concept sketch](image-url)
It is also possible to use only the top and the bottom piece; it would not provide much extra weight, but more than enough to make the pipes sink. This is shown in figure 6.8.

Figure 6.8 Minimum sized weight situation
7. Analysis

In this chapter, the results and the corresponding theory are evaluated. It is analyzed how well the two comply with each other. It is also analyzed why certain results deviate from the theory regarding the same matter.

7.1 Lifetime results

The lifetime results had well corresponding theory, the deviations that appeared are mostly due to special investigations of phenomena’s that are new theories and therefore is not considered as reliable theory.

7.1.1 Polypropylene lifetime

The results on lifetime show that polypropylene (PP) can last for a very long time, (340 years at 40° C, and 3400 years at 20° C). This proves the theory that polypropylene, or plastics in general, degrade very slowly. Some special condition research like Carbon Black additive resulting in the plastic being attacked by galvanic corrosion appeared in the results and this risk was not considered within the theory of this report.

7.1.2 Concrete lifetime

Regarding life length of concrete the theory as well as the result of this report regards the reinforcements that are generally used in the material and often consist of metal. The result shows more deep-going theories about the long-time effects of corrosive reinforcements, but the correspondence between theory and results are considered very promising.

7.1.3 Cast Iron lifetime

The results are very similar to the theory concerning the life length of cast iron in subsea environments. The corrosion values, millimeters per year and similar measurements, are widely ranging due to many factors. Since no specific corroding circumstances, except subsea environment, where determined, the results are considered to be reliable when cross-referencing to the theory concerned.
7.2 Environmental aspect

Environmental impact can be measured in many ways, and there are several parameters that can be included in some calculations but not in others.

7.1.1 Plastics

The environmental impact is large from the manufacturing of plastics; this is a value that both tests and theory verify. However, the recently reported facts presented in the results determine that the plastics that are mechanically recyclable hold great environmental advantages towards other materials.

Recent test results prove that the properties of the polymers are lowered in the recycling process, but occasionally the properties are left unchanged. The theory regarding this says that recycling processes are sensitive to impurities, which can lead to possible mechanical properties e.g. tensile strength of the plastic to be lowered.

7.1.2 Concrete

The concrete is a very environmental friendly material to choose, compared to other materials when counting kg CO₂ –emissions / kg material. This is stated in the theory and well confirmed by the results in this field.

In Appendix 4 a concrete material declaration can be seen, it is declared that 5.1kg CO₂/ tonne are emitted. This value is only regarding direct emissions and no energy consumption included, the energy consumption is specified to 151 MJ/ tonne (41.94 kWh) concrete manufactured, using electricity and oil. These values approximately result in emissions of 35kg CO₂/ tonne concrete manufactured.

This value is very low compared to the similar study in “Journal of Cleaner Production”[84]. Note that the study calculated with CO₂/ m³ while the material declaration in Appendix 4 is concerning CO₂/ tonne. If a density of 2400 kg/m³ is used (which is normal for concrete[16,26]), the total emissions from the material manufacturing are estimated to around 84 kg CO₂/ m³.
This value is still very low and possible reasons for the deviation could be:

- Favorable measurements from the manufactures
- Low amount of Cement used in the concrete mix
- Parameters that should have been included was not accounted for

7.1.3 Cast Iron

The manufacturing of Iron and steel requires a lot of energy, due to the high temperatures. The material is in theory considered to have very high impact on the environment because of this. However, recent research shows that there are modern alternatives to achieve the same temperatures with a lot lower impact on the environment. It should be noticed that these results of lower emissions also leads to more expensive manufacturing and, on top of that, huge investments are required to change the heating process in concerned facilities.

7.3 Snapp Panzar

Snapp Panzar is the new product and the opportunities and possible applications are considered for it. The different situations are evaluated and compared with aspect to the strengths and weaknesses of Snapp Panzar.

The materials elasticity can be adjusted with the amount of EPDM in the blend, which is explained in the theory, and also in the current situation analysis of this report. These facts are verified by test results of polymer blends with varying EPDM – content.

7.3.1 Applications

Snapp Panzar - positive features, compared to other products:

- Circulation holes
- Easily snapped around the cable
- High strength/weight - ratio
- Degradation resistant material
- Elastomeric behavior (not sensitive to impacts)
- Environmentally friendly (as long as recycled plastic is used)
- Low material cost
Snapp Panzar - Negative features:

- Sensitive to creeping, permanent set
- Low tensile strength compared to other materials (volume dependent)
- Density lower than water
- The only available length is 1 meter

The applications that exist are then cross-referenced to these features to analyze which applications are more or less suitable for Snapp Panzar.

7.3.1.1 Offshore cable installations – long distances

In the situation when cables are installed over long distances, the possibilities to evade unfavorable seabed topography’s are relatively good. The use for Snapp Panzar in these situations is mainly as a complements and at specific situations. Under normal conditions, it would take too much time and funding’s to motivate an installation of one meter long protective pipes.

The most common failure reason for these offshore long-distance cables are anchors ripping them apart. This cannot be prevented by Snapp Panzar, but if ships in the future take precautions and avoid destroying the offshore grid, Snapp Panzar could be more useful.

It is important in this application to achieve a long life of the cable, and the protective solution must remain for a long time as well. The polypropylene of Snapp Panzar is very degradation resistant compared to the e.g. concrete mattresses that are today used in situation where the cable cannot be buried.

The situation where sand is used along with a woven mat to protect the cable from the crushed rocks that are used to cover the cable is a very inefficient solution. In this case Snapp Panzar could replace the current method, with improved life length and installation time, to a reduced price. It should however be noticed that the method is inefficient to the point that it could be replaced by most methods.

7.3.1.1 Cable installations within offshore wind farms

Cables within wind farms today demand high quality; the recycled plastic of Snapp Panzar could be seen as a threat to these quality demands. If the quality however could be guaranteed, it sounds very reasonable to use recycled environmentally friendly material to construct renewable energy facilities.
Offshore wind farms are constantly increasing in size and efficiency, this result in more energy being transported from the wind farms constantly. The constant high energy transportation require most of all a very reliable grid. The dominating manufacturers for these protective solutions are working in polyurethane, a very special material. The best solution would probably be to investigate each section of the wind park, and use Snapp Panzar in combination with the polyurethane solutions.

One possible situation for Snapp Panzar within a wind farm is to protect the cables on the seabed, depending on the difficulties to bury the cable between each connection. This would require a joint sleeve to be developed to connect the different solutions to each other.

### 7.3.2 Calculated values

The loads applied to the pipes are in theory no problem; the only thing that could occur is long time set – creeping in the material. This is verified in the result through calculations; certain safety factors have inevitable been included. These inevitable safety factors along with the many assumptions (worst case scenario assumed) are probably the reason to any deviations between theory and calculations.

The values from the calculated impact strength are considered very reliable and that the tests only consider a falling mass of 10 [kg]. Meaning the mass is not increased until the test specimen fail.
8. Discussion

In this chapter the results from the report are discussed, also the approach in the investigations is discussed as well as used methods. The writer’s opinions in different matters shine through in some matters.

8.1 Material comparison

A material comparison between Cast Iron, Concrete and Plastic like PP blends or PE blends seems to be suitable in these times. Indications are that it is a well discussed matter, especially when it comes to sewer pipes and pressure pipe constructions. The results indicate that the pipes could be used in all three materials despite the different properties they at first seem to have. The question to ask when choosing material seems to be how the surrounding environment looks like. Reports for all three materials indicate that degradation of them may vary a lot from situation to situation. It appears to be the constructors experience in the field that is the definite factor for decision making.

8.1.1 Long-term perspective

The concern in a long term perspective is for concrete if the reinforcements are exposed from e.g. a stroke from a boat anchor or the like, the corrosion of the reinforcements is then inevitable and it will not take long before the concrete structure is destroyed. In situation where it is possible to use non-reinforced concrete it has a noticeable advantage because it seems to have a very long life time. According to interviews with Jan and Fredrik showed in appendix 5 the concrete structure can last at least 50 years, up to a hundred and even more.

For cast iron the important question is the protective coatings that will extend the life time for the material, if the coating should be damaged the material will start to corrode immediately and with concern for the pitting corrosion it will not take long before the pipes are damaged in a significant way. If regular maintenance is not possible cast iron may be a bad choice in the long-term.

For the plastic pipes the concern is if there is risk for accelerating causes for degradation e.g. acids or other substances that could break down the plastic structure. It is also a matter of temperature. Plastics are sensitive for both high and low temperatures as well as temperature changes. The blend should be adapted to the environment it is supposed to be in. The plastic seems to last at
least the required time for cable protectors in the harsh environment at the seabed.

The choice of material when it comes to strength abilities and life time prediction is all up to the situation. Every situation should be evaluated in terms of risks for impact, expected life time, surrounding environment and what level of protection that is needed. Maybe a combination of two may be an option.

8.1.2 Environmental perspective

In the environmental investigations the emission of carbon oxide in the manufacturing process was studied. The results differed quite much. But there is more to be done in this area. Not only carbon oxide is emitted in the different manufacturing processes. Other emissions are equally important to investigate. And also the impact of the environment when the different materials are in use in their right application is important to evaluate.

The environmental effect from the different materials are considered not to affect the subsea plant- and animal life in a remarkable way in comparison to the effect the installation of the cables has on the environment. The digging in the seabed\(^7\) destroys the life where it is performed but it recovers when the cable and the cable protectors are in place. Unfortunately there has not been much research in this area and the possibility that particle from the cable protection pipes losses and affects the surroundings is an eventuality that should be considered.

Further on can following question be important to answer in an environmental investigation between different materials: Is it continuously emissions from the construction? What happens with the material when the construction is no longer in use? Can the material be recycled? The environmental impact from the different materials should be analyzed more to get a fair picture of the situation.

8.2 Snapp Panzar material evaluation

It was shown not to be an easy task to analyze plastic materials and the seemingly endless mix of different polymers and additives that are used in different blends and applications. After having familiarized with the basics of plastic components the work started to sort out and understand the impact different additives have on plastic mixtures. Additives have been examined by literature studies and from previous tests. The results show that small changes in
a plastic mixture may change the properties significantly. All depending on the choice of additive, amount of additive and even the way that it is added to the mixture. It is an extensive work to find the right blend with desired properties. This is also confirmed by listening to professionals in the business as seen in the interview with Leif Pettersson \cite{91} in Appendix 8. Leif has over 40 years of experience from the plastic industry and have been a great help and supervisor in this project.

One can have opinions about how the work to find good additives and get a suitable plastic blend for the plastic pipes in this report has been done. Of course testing of different blends with different additives would have been preferable to ensure that the properties of the pipes would be the very best. Unfortunately there was no time or right equipment for such tests. The recommendation we send to the company Snapp is to continue experiment with different blends and additives and make proper standardized tests at recognized companies like SP – Technical research institute of Sweden, to ensure the good quality that already can be found in existing pipes.

As part of the evaluation of the plastic blend we made research on existing tests for polypropylene materials. Of particular interest was the study of ageing and how that affected the properties of the material and also how the material managed in a long term perspective. The result from this was overwhelming when a result for at least 300 years in a submarine environment comes up. Even an error factor of 5 will give a life length of 60 years and meet the requirement of 50 years. This is however not a shocking result when listening to Leif\cite{91} and his convincing opinion that the plastic blend does not decompose at all in our lifetime. And also Lars Petterson\cite{93} experience (Appendix 6) is that no degradation of the plastic is seen while the metal components like bolted joints needs to be replaced.

The results for the plastic pipes should remove any doubts that it is suitable as submarine protection. Maybe not in every situation where demands for strength properties are especially high but in selected ones it is no doubt that they will be enough and especially in a long term perspective.
9. Conclusions

The choice of material for submarine cable protection must be made in respect to the surrounding environment. The materials survivability varies in different environments. The priorities in the certain situation are also a deciding factor.

Location and size of the cable that needs to be protected is an important question. Higher demands on protective cover are held for cables in the national grid. In this case, the concrete mattress is advantageous due to its good strength, sustainability and good long-term abilities. In smaller grids and on a seabed with harsher conditions, the plastic pipes are preferable due to the light weight and the different options during installation.

Concrete is the most environmental friendly choice with respect to CO₂ emissions. More research should be done for other types of emissions. With the use of recycled material the situation is another. Plastic manufacturers have the most to gain from using recycled material, due to the low melt temperature. Mechanical recycled plastics are the considered option. More studies should be done in the field for exact results since recycling is preferable with respect to the environment.

Snapp Panzar in a polypropylene plastic blend is well suited as an offshore cable protective pipe. The life length exceeds the required time for the cable in subsea environment. It is good to have the approach that it is not perfect in every situation but it should definitely be considered as an option or supplement to several other products used today.

Snapp Panzar needs to be complemented with other products like the sea weight if the company wants to develop and be a part of the submarine cable protection industry. In offshore wind farm applications it needs to be complemented with parts connecting to the wind turbine.
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11. Appendixes

Appendix 1: Thermal data – plastics

Appendix 2: Electrochemical voltage series

Appendix 3: Snapp Panzar molds – first pictures

Appendix 4: Study trip to “Plastteknik Nordic”

Appendix 5: Interviews regarding concrete

Appendix 6: Interview with Lars Pettersson’s diving team 2014-05-13 Karlskrona

Appendix 7: Interviews with civil engineer Gunnar Gehlin at Svenska kraftnät 2014-04-22 and 2014-05-15

Appendix 8: Continuous interview with Leif Pettersson 2014-03-31 to 2014-05-26

Appendix 9: Test Data from SP, Ring stiffness

Appendix 10: Declaration of construction materials, concrete
APPENDIX 1

Thermal data -plastics

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Niklas Svensson, Martin Holmberg
APPENDIX 2

Electrochemical voltage series \[1.7\]

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<tr>
<td>Gold</td>
<td>Au ⇌ Au^{3+} + 3 e⁻</td>
<td>+1.50</td>
</tr>
<tr>
<td>Chlorine (Klor)</td>
<td>2 Cl⁻ ⇌ Cl₂ + 2 e⁻</td>
<td>+1.3595</td>
</tr>
<tr>
<td>Vatten</td>
<td>H₂O ⇌ O₂ + 4 H⁺ + 4 e⁻</td>
<td>+1.229</td>
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<tr>
<td>Brom</td>
<td>2 Br⁻ ⇌ Br₂ + 2 e⁻</td>
<td>+1.0652</td>
</tr>
<tr>
<td>Kvameoxid</td>
<td>NO + 2 H₂O ⇌ NO₃⁻ + 4 H⁺ + 3 e⁻</td>
<td>+0.96</td>
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<tr>
<td>Silver</td>
<td>Ag ⇌ Ag⁺ + e⁻</td>
<td>+0.7991</td>
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<tr>
<td>Kvicksilver</td>
<td>2 Hg ⇌ Hg₂⁺ + 2 e⁻</td>
<td>+0.793</td>
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<tr>
<td>Jarn</td>
<td>Fe²⁺ ⇌ Fe³⁺ + e⁻</td>
<td>+0.77</td>
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<tr>
<td>Jod</td>
<td>2 I⁻ ⇌ I₂ + 2 e⁻</td>
<td>+0.5865</td>
</tr>
<tr>
<td>Koppar</td>
<td>Cu ⇌ Cu⁺ + e⁻</td>
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<tr>
<td>Vatten</td>
<td>4 OH⁻ ⇌ O₂ + 2 H₂O + 4 e⁻</td>
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<tr>
<td>Koppar</td>
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<tr>
<td>Svavelsyra</td>
<td>H₂SO₄ + H₂O ⇌ SO₄²⁻ + 4 H⁺ + 2 e⁻</td>
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<tr>
<td>Väl</td>
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<td>Bly</td>
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<tr>
<td>Tenn</td>
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<td>Nickel</td>
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<tr>
<td>Kobolt</td>
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<td>Kadniun</td>
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<tr>
<td>Cesium</td>
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<tr>
<td>Litium</td>
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<td>-3.045</td>
</tr>
</tbody>
</table>
APPENDIX 3

Snapp Panzar molds – first pictures
APPENDIX 4

Study trip to ”Plastteknik Nordic”

The 10/4 -2014 we traveled to Malmö to visit the largest plastic fair in Scandinavia, “Plastteknik Nordic”. The purpose of this trip was to see and meet companies who work with plastics every day, and also to see different solutions and possibilities with plastic constructing. On this fair there was many different kind of companies that worked with plastic in all kind of ways; software developers, manufacturers, recycling companies, testing facilities, constructors etc.

We talked to several companies, most had their own products but some companies that we found were skilled in testing of different plastic blends, which we believe can help us in this study.

The companies that we found most interesting and decided to find more information about are:

**Plasticson** – Software Development Company provides comprehensive information about plastic used as raw material. All material gathered in one place, a program that replaces long paper sheets with plastic properties, diagrams, tables etc. Some of the information that their program provides are:

- Technical information for the most common plastics, including melt processing parameters, surface tension and toughness in cold.
- Raw material price and a comparison feature were you can select relevant plastics and their properties.
- This company’s services can be interesting for Snapp depending on how well developed the possibility to find properties for new plastic blends are.

**SP** – Technical Research Institute. The SP-group consists of 10 different corporations. The parent corporation is “SP- Sveriges tekniska forskningsinstitut AB”. Snapp have already been in contact with this company to get their conduits classified in the SR-standard. They also want SP to do some additional testing for their products in the future, allowed working temperature among more.

We will use information, if possible, from this company, how they perform the different tests, and also results from testing, both for plastics but possibly also
for testing they made on concrete and cast iron pipes. Their limits for different classifications can also be of interest for this report.

**Cromocol** – This company focus is on testing equipment for many different branches, plastic is the one that is of interest in this report. They provide both tests for new plastic blends, (like SP) but also sell equipment and instruments to companies who want to perform tests of their own. The properties their equipment is designed to test, and which also are of interest for this report, are:

- Weather resistance
- Corrosion
- Abrasion
- Climate variation effects
- Scratch resistance / surface strength

This company can be considered as an alternative for SP in the future and therefore are a very interesting company for Snapp. It is also possible that Snapp in the future will buy their own test equipment.
APPENDIX 5

Interviews regarding concrete

As a part of the evaluation of concrete as an alternative for cable protection on the seabed contact was taken with two companies, A-betong in Växjö and Meag Va-system that is located in a few places in southern Sweden. The purpose was to gather opinions from experienced people regarding the concrete.

Interview with Jan Lillieblad at A-betong 2014-04-29 Växjö

Contact with Jan resulted in this questions and his answers regarding concrete and its application in salt water. The questions and answers were sent via mail.

Questions:

1. Are concrete decomposed in water over time with worsen properties as a result?
2. What "symptoms” can be seen in the concrete if it starts to decompose?
3. What makes it decompose?
4. What life length does concrete have on the seabed, (4° C)?
5. Are the concrete affected differently with various salinity or bacteria in the water?
6. What does it cost to manufacture a concrete pipe with an inner diameter of around 30 cm and length 1 m?
7. What environmental impact does concrete have?
Answer:

Durability: If using the right quality of the concrete it holds very long: 50 - 100 years. Sulfates and chlorides in seawater attack the concrete and its reinforcement. Sulfates loosen the concrete surface and chlorides cause the reinforcement to corrode. One must use a sulfate-resistant cement type Cementa construction cement. Moreover, one should not have too much water in relation to the cement. Water / cement <0.4. You also need an enough thick concrete layer that protects possible reinforcement. Taking these things in consideration the concrete will last very well in the marine environment.

Jan had no answer on question number 5 and he referred to a homepage regarding the environmental impact from concrete products. (See reference 26)

This information is handled in environmental aspects of concrete in the theory part.
Interview with Fredrik Molander at Meag VA-system 2014-05-12 -Huddinge

Regarding particularly the pipes in concrete we were recommended to contact Meag

1. **What would you say is the life length of a concrete pipe in a harsh environment, especially on the seabed, reinforced and not reinforced?**

Unreinforced concrete pipes has an almost indefinitely life length in both salt and fresh water. Reinforced pipes are worse in saltwater then the ones without reinforcement; our armored pipe meets the requirements for life length class L50 (50 years) with respect to salt water, however, the life length is significantly longer in reality. Concrete products are generally sensitive to low pH values.

2. **Are the concrete affected differently with various salinity or bacteria in the water?**

Marginally

3. **What environmental impact does a concrete pipe have?**

Low

4. **What is the manufacturing cost of a concrete pipe reinforced / unreinforced, inner diameter of around 30 cm, length 1 m?**

A common price for customer is about 400 SEK for a pipe as above; however, prices can vary greatly depending on contracts, volume, items, etc.
5. *If you have any test results or material tables for impact strength and other mechanical properties, we would like to take part of them in our material comparison.*

Our concrete for pipes meets strength class C40/50. We have not carried out any testing for impact strength. The pipes shall withstand a certain load that is dependent on the pipe dimension, according to formula in Swedish standard SS 22 70 00:

\[
\text{Strength class} \times \frac{\text{Dimension [mm]}}{1000} \quad \text{[kN/m]}
\]

Fredrik referred to their “declaration of construction materials” regarding the environmental impact. (See appendix 4) This information is handled in environmental aspects of concrete in the theory part.
APPENDIX 6

Interview with Lars Pettersson’s diving team 2014-05-13 Karlskrona

To receive opinions from the people working with the installation of pipes in an underwater environment, we visited three divers who are employed by the municipality of Karlskrona Sweden. These people work daily with the planning and execution regarding installation of cables and pipes for energy supply and sewerage systems. The systems they are working with are of smaller size up to 10 km long and meant for normal households. We had a talk with these people and received a lot of useful information from experienced professionals. The substance of the conversation and there answers for our questions is shown here.

- We have not had any problems with ageing and broken plastic pipes since -68 when we installed our first plastic pipe.
- The metal that is a part of the construction, for example bolted joints that join two pipes together does not last for required 50 years
- Even though we use the more expensive alternatives for the metal part it will not last
- We rather not use any metal protecting the cables and pipes because of our experience that it will corrode and be useless.
- It is important that the protection pipes can float when using them in an application for a sewer system because of the formation of air bubbles in the system that is naturally removed when the pipes lifts from the seabed and the air bubbles moves further away in the system and eventually finds its way out
- For our small systems that are installed by hand plastic protection pipes is the best option because of the easy handling and low weight
- We rather not use any metal protecting the cables and pipes because of our experience that it will corrode and be useless
- When we can’t bury the cable under the seabed because of hard terrain and when we come close to land and in the connection between land and sea we need to use protection for the cable or sewer pipes because of the risk of a damaged cable/pipe
- We have measured a temperature of -0,9°C as far down as 15 meters below the surface.
APPENDIX 7

Interviews with civil engineer Gunnar Gehlin at Svenska kraftnät
2014-04-22 and 2014-05-15

This interview was made with the purpose to find out more about cable protection in offshore applications. The answers regard bigger cables that are drawn longer distances, for example between Sweden and Denmark or between the mainland and the island Gotland 100 km outside Swedish coastland.

1. **How is the cable protected on the seabed?**

The cable is normally buried 1-2 meters down below the seabed. When this is not possible it’s covered with rocks or a concrete mat or similar. The cable also has armoring in steel or aluminum.

1. **Which method is used when the cable is buried?**

Different methods depending on what kind of seabed it is. If it is sandy or muddy a water-jetting method is used. If it is a harder bottom in shallow water its dig down with an excavator on a barge. And when deeper water it’s plowed with a plow connected to a boat.

2. **How long time is it before the cable must be replaced?**

The cable could last a very long time, we expect it to last at least 40 years but believe it could last between 60-100 years but it depends if it’s damaged anyway during this time.

3. **How can the cable be damaged?**

The cable is buried in a depth that shall protect it from the anchors from smaller boats but from larger ships it is not possible to do that. There we have to trust the skipper not to lay anchor where the cables are located. But when it still happens it can be damaged.

4. **How is it determined when the cable must be replaced?**

We don’t do any scheduled controls of the cable, for example, every eight years but if the cable repeatedly shows problem we make controls of it and then determine if it needs to be replaced.
5. *What life length do you expect a cable to have?*

If nothing unexpected happens at least 50 years.

6. Are you using pipes of any kind as protection for cables, maybe as extra protection when it’s close to land? Or is it only concrete mattresses and crushed stone that are used?

For the big and important cables that are included in (belongs to) the national grid, we set higher standards than what you normally do on the "smaller" cables at lower voltage levels. For the laying of submarine cables "in the country" in small lakes, rivers and similar, we can certainly use pipes to protect the cables. But when it comes to "real" submarine cables at sea and also near the beach, I am hesitant to just put them in a pipe. We would like to have a better / safer protection. Like flushing, burial, coverage with rocks or concrete mattresses or similar. Possibly, one could imagine laying the pipe in combination with another method at some point?
APPENDIX 8

Continuous interview with Leif Pettersson 2014-03-31 to 2014-05-26

Leif has a lifelong experience from the plastic industry and has knowledge about plastic we could never achieve from just reading literature. We have had two conversations with Leif regarding the art of plastics including plastic blends, manufacturing, additives, ageing etc. The following is the information and opinions we have received orally from Leif.

- Snapp products plastic pipe has a very long life length in an offshore application
- There is nothing really that can affect the plastic in a submarine environment in a way that makes the plastic age with worsen properties in at least 50 years’ time.
- Carbon black is an additive that mainly is used to make the plastic resistant to UV light. It cannot be used as reinforcement in the plastic blends.
- Testing is required on the certain plastic blend that is in use, properties could shift a lot in another plastic blend.
- The work to find a suitable plastic blend may require extensive efforts in both money and time.
APPENDIX 9

Test Data from SP according Ring stiffness

Testometric
materials testing machines

TEST REPORT EN 61966-24
EVOCAB SPLIT NEW SRN 75N

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Outer Diameter (mm)</th>
<th>Inner Diameter (mm)</th>
<th>Total Length (mm)</th>
<th>Force (kN)</th>
<th>Deflection (mm)</th>
<th>Inner Diameter (mm)</th>
<th>Test 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>8</td>
<td>60</td>
<td>0.189</td>
<td>0.59</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

Temperature: 23.6°C; Relative Humidity 55.9%
TEST REPORT EN 81366-24
EVOCAB SPLIT NEW SRS 1250N

Name: EVOCAB SPLIT NEW
Diameter: DN110 mm
Weight: 
Batch number: T28361/PH2333

Test Name: IN DIAM DN(10-160) EN61366-24
Test Type: Step Compression
Test Date: 19/02/2014 13:27
Preload Speed: 15.000 mm/min
Preload: 2.000 N
Transducer: Digital Compressometer

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Outer Diameter (mm)</th>
<th>Inner Diameter (mm)</th>
<th>Lip Length (mm)</th>
<th>Force @Peak</th>
<th>Deformation @ Inner Diameter (mm)</th>
<th>Force @Break</th>
<th>Deformation @ Inner Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>114.020</td>
<td>95.000</td>
<td>150.000</td>
<td>794.500</td>
<td>58.051</td>
<td>85.046</td>
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</tbody>
</table>

![Graph of Load vs Deflection](chart.png)
TFST REPORT EN 61396-24

Test Name: IN DIAM DN(10-160) EN61396-24
Test Type: Step Compression
Test Date: 19/02/2014 13:33
Preload Speed: 15.000 mm/min
Preload: 2.000 N
Transducer: Digital Compressometer

Sample Code:    Core Diameter  Inner Diameter  Pipe Length  Force (g)  Peak Diametral
                (mm)             (mm)            (mm)             (kN)      (mm)
1                103.750        142.500        202.500        855.460    7.130

-- Test --
**Testometric**
materials testing machines

TLSI REPORT LN 61386-24
EVOCAB SPLIT NEW SRN 750N

Name: EVOCAB SPLIT NEW  
Diameter: DN160 mm  
Weight:  
Batch number:  

Test Name: IN DIAM DN(10-180) EN61386-24  
Test Type: Step Compression  
Test Date: 19/02/2014 13:30  
Preload Speed: 15,000 mm/min  
Preload: 2,000 N  
Transducer: Digital Compressometer  

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<th>Outer Diameter (mm)</th>
<th>Inner Diameter (mm)</th>
<th>Pitch Length (mm)</th>
<th>Force @ Peak (kN)</th>
<th>Deflection @ 0.200% (mm)</th>
<th>Deflection @ 0.500% (mm)</th>
<th>Deflection @ 1.000% (mm)</th>
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<tbody>
<tr>
<td>1</td>
<td>160.150</td>
<td>141.540</td>
<td>290.000</td>
<td>9.092</td>
<td>0.034</td>
<td>0.083</td>
<td>0.134</td>
</tr>
</tbody>
</table>

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![Graph showing force vs. deflection](image-url)
Name: EVOCAB SPLIT NEW
Diameter: DN60 mm
Weight: 
Batch number: 

Test Name: IN DIAM DN(10-160) EN61386-24
Test Type: Step Compression
Test Date: 19/02/2014 12:55
Preload Speed: 15.000 mm/min
Preload: 2.000 N
Transducer: Digital Compressometer

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Outer Diameter (mm)</th>
<th>Inner Diameter (mm)</th>
<th>Flat Length (mm)</th>
<th>Force (kN)</th>
<th>Extent (mm)</th>
<th>25% Extent (mm)</th>
<th>50% Extent (mm)</th>
<th>75% Extent (mm)</th>
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<tbody>
<tr>
<td></td>
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<td>41.240</td>
<td>198.002</td>
<td>770.00</td>
<td>2562</td>
<td>9868</td>
<td>12397</td>
<td>12700</td>
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### APPENDIX 10

Declaration of construction materials, concrete

---

**BYGGVARUDEKLARATION BVD 3**  
enligt Kretsloppsådets riktlinjer maj 2007

#### 1 Grunddata

<table>
<thead>
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<th>Produktidentifikation</th>
<th>Dokument-ID RRD 13 v1</th>
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<td>Varumärk</td>
<td>ALFA</td>
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<tr>
<td>Artikel-ID/begrepp</td>
<td>Varugrupp</td>
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<tr>
<td>Rör och rördelar</td>
<td>PBB, PBF</td>
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<tr>
<td>Ny deklaration</td>
<td>Vidändrad deklaration</td>
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<tr>
<td>Upprättad/ändrad den</td>
<td>2013-09-27</td>
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Övriga upplysningar: Deklarationen omfattar rör och rördelar som tillverkas av ALFA RÖR ABs deltagare under varumärket ALFA.

#### 2 Leverantörsuppgifter

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<thead>
<tr>
<th>Företagsnummer</th>
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<tbody>
<tr>
<td>Adress</td>
<td>Box 1230</td>
</tr>
<tr>
<td>141 80 Huddinge</td>
<td></td>
</tr>
<tr>
<td>Webplan</td>
<td>alfaror.se</td>
</tr>
<tr>
<td>E-post</td>
<td><a href="mailto:info@alfaror.se">info@alfaror.se</a></td>
</tr>
<tr>
<td>Organisationsnr/DUNS-nr</td>
<td>556102-7081</td>
</tr>
<tr>
<td>Kontaktperson</td>
<td>Fredrik Molander</td>
</tr>
<tr>
<td>Telefon</td>
<td>09-774 02 80</td>
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#### 3 Varuinformation

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<td>Vatten och avtipp</td>
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<td>Förricesortering upp Hög färdig for vara</td>
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#### 4 Innehåll

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<th>Ingående material/ Komponenter</th>
<th>Ingående ämnen</th>
<th>Vkt % alt g</th>
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<th>Klassificering</th>
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Uppgifter i grönmarkerade fält är krävande Kretsloppsådets riktlinjer.

---

Niklas Svensson, Martin Holmberg
### Produktionsskedet

#### Ressursnätverksanalyser och miljöpåverkan under produktion av varan redivisas på ett av följande sätt:

- **1)** Införd (rivaror, insatsvaror, energi mm) för den registrerade varan till tillverkningseinhetens, och utföden (emissioner och restprodukter) därifrån, d.v.s från "grind till grind".
- **2)** Samtliga inföden och utföden från utvinning av rivaror till färdig produkt d.v.s "vagga till grind".
- **3)** Annan avgränsning. Ange vad:

<table>
<thead>
<tr>
<th>Redovisningen avser enhet av varan</th>
<th>Redovisad vara</th>
<th>Varans varugrupp</th>
<th>Varans tillverkningseinhet</th>
</tr>
</thead>
</table>

- **Aga rivaror och insatsvaror som använts vid tillverkning av varan**
  - Mängd och enhet
  - Kommentar

- **Aga återvunna material som använts vid tillverkning av varan**
  - Mängd och enhet
  - Kommentar

- **Aga energi som använts vid tillverkning av varan eller dess delar**
  - Mängd och enhet
  - Kommentar

- **Energislag**
  - Mängd och enhet
  - Kommentar

- **Ej och olja**
  - 151 MJ/ton

- **Aga transporter som använts vid tillverkning av varan eller dess delar**
  - Mängd och enhet
  - Kommentar

- **Transportslag**
  - Andel %
  - Kommentar

- **Lastbil**
  - 100
  - Diesel

- **Aga emissioner till luft, vatten eller mark från tillverkning av varan eller dess delar**
  - Mängd och enhet
  - Kommentar

- **Emissionslag**
  - Mängd och enhet
  - Kommentar

- **CO₂**
  - 5.1 kg/ton
  - Till luft

- **NO₂**
  - 26 g/ton
  - Till luft

- **SO₂**
  - 12 g/ton
  - Till luft

- **Aga restprodukter från tillverkning av varan eller dess delar**
  - Mängd
  - Andel som återvinningsavfall
  - Materialåtervinnings-%
  - Energialternativ-
  - Kommentar

- **Fins dataomgivningen för tillverkningseinhetens beskrivning?**
  - Ja / Nej
  - Om "ja", specifika:

Övriga upplysningar:

**Uppgifter i grönmärkade fält är krav enligt Kretsloppsårets riktlinjer.**
6 Distribution av färdig vara

| Tillskrivs leverantören retursystem för lastbara av varan? | ☐ Ej relevant | ☑ Ja | ☐ Nej |
| Tillskrivs leverantören system med färgeramsenbalage för varan? | ☑ Ej relevant | ☐ Ja | ☐ Nej |
| Återleverantören embalage för varan? | ☑ Ej relevant | ☐ Ja | ☐ Nej |
| År leverantören ansluten till REPA? | ☐ Ej relevant | ☐ Ja | ☐ Nej |
| Övriga upplysningar: |

7 Byggskedet

| Ställer varan särskilda krav vid lagring? | ☐ Ej relevant | ☐ Ja | ☐ Nej | Om "ja", specificera: |
| Ställer varan särskilda krav på omgivande byggaror? | ☐ Ej relevant | ☐ Ja | ☐ Nej | Om "ja", specificera: |
| Övriga upplysningar: |

8 Bruksskedet

| Ställer varan krav på innehavare för drift och underhåll? | ☐ Ja | ☑ Nej | Om "ja", specificera: |
| Ställer varan krav på energiärsförsörjning för drift? | ☐ Ja | ☑ Nej | Om "ja", specificera: |
| Uppskattad teknisk livslängd för varan anges enligt ett av alternativen a) eller b) nedan: |
| a) Referenslivslängden uppskattas vara cirka | ☐ 5 år | ☐ 10 år | ☐ 15 år | ☐ 25 år | ☑ >50 år | Kommentar |
| b) Referenslivslängden uppskattas vara i intervallet | ☐ | ☐ | ☐ | ☐ | ☑ | |
| Övriga upplysningar: |

9 Rivning

| Är varan förberedd för demontering (inläggning)? | ☐ Ej relevant | ☐ Ja | ☑ Nej | Om "ja", specificera: |
| Kräver varan särskilda åtgärder för skydd av hälsa och miljö vid rivning/demontering? | ☐ Ej relevant | ☐ Ja | ☑ Nej | Om "ja", specificera: |
| Övriga upplysningar: |

10 Avfallshantering

| Är återanvändning möjlig för hela eller delar av varan? | ☐ Ej relevant | ☐ Ja | ☑ Nej | Om "ja", specificera: |
| Är materialåtervinning möjlig för hela eller delar av varan? | ☑ Ej relevant | ☐ Ja | ☑ Nej | Om "ja", specificera: |
| Är energiåtervinning möjlig för hela eller delar av varan? | ☐ Ej relevant | ☐ Ja | ☑ Nej | Om "ja", specificera: |
| Har leverantören restriktioner och rekommendationer för återanvändning, material- eller energiåtervinning eller deponering? | ☐ Ej relevant | ☐ Ja | ☑ Nej | Om "ja", specificera: |
| Aage avfallsdel för den levererade varan Betong 170101, Armeringsstål 170405, Gummi och plast 181204. | |
| Är den levererade varan klassad som farligt avfall? | ☑ Ja | ☐ Nej |
| Om varan kan kemi hotelsbehandling är anmänt under leverans, och den färdiga inbyggda varan därmed får en annan avfallskod anges den här. Om den är oförändrad upptäcks nedanstående uppgifter. |
| Aage avfallsdel för den inbyggda varan | |
| Är den inbyggda varan klassad som farligt avfall? | ☐ Ja | ☑ Nej |
| Övriga upplysningar: |

Uppgifter i grönmärkade fält är krav enligt Kretsloppsrådets riktlinjer.
## 11 Innemiljö

<table>
<thead>
<tr>
<th>Typ av emission</th>
<th>Mängd [μg/m³ h] alt [mg/m³ h]</th>
<th>Mätmetod</th>
<th>Kommentar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 veckor</td>
<td>26 veckor</td>
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</table>

- Kan varan ge upphov till eget buller? □ Ej relevant □ Ja □ Nej

- Virde
- Enhet
- Mätmetod:

- Kan varan ge upphov till elektriska fält? □ Ej relevant □ Ja □ Nej

- Virde
- Enhet
- Mätmetod:

- Kan varan ge upphov till magnetiska fält? □ Ej relevant □ Ja □ Nej

- Virde
- Enhet
- Mätmetod:

**Övriga upplysningar:**

**Hänvisningar**

**Bilagor**
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