Technology and Market Study on Continuous Casting Rolls

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Abstract

This Master’s Thesis consists of two separate and independent studies: One metallurgical study and one industrial buying behaviour study. Both studies concern continuous casting rolls.

Metallurgical Study

The first objective of this study was to investigate two continuous casting rolls, consisting of different steel tubes with different martensitic stainless steel weld overlays. The second objective was to evaluate the methods employed in the study.

The weld overlaps are clearly the weakest points of the weld overlay. They are sensitive to corrosion attacks, mainly due to sensitisation. The delta ferrite present in the welded overlay of both rolls is a preferential site for the corrosion attacks and the delta ferrite content depends primarily on the chemical composition of the weld overlay. The welding temperature may also have some influence on the delta ferrite content, but this has not been observed in this study. Both rolls have similar surface hardness. Roll no. 2 has more generalized corrosion attacks than roll no. 1. This is due to a higher delta ferrite content in roll no. 2 than in roll no. 1.

The methods employed during the study proved to be adequate. In any future study, on condition that the visual inspection, diameter measurements, ultrasonic testing and surface hardness measurements show that all positions on the roll are similar, it will be sufficient to cut a bead and overlap sample from only one position.

The rolls were investigated using macro etching, optical microscopy, Vickers hardness testing, ultrasonic testing ICP-OES analysis of nickel and chromium content and carbon content analysis by wet chemical method. Delta ferrite content was also calculated theoretically using a Schaeffler – DeLong diagram and a semi-empirical model.

Industrial Buying Behaviour Study

The aim of this study is to investigate the industrial buying behaviour in slab casting steelworks in Western Europe when buying roll-lines. Case studies have been conducted at four steelworks belonging to different companies. Data was collected through personal interviews with people from production, maintenance and purchasing department and intermediate level management.

A test consisting of a smaller amount of rolls is always performed before buying any larger quantities of rolls. Even though the test order has relatively low economic value, compared to a full-scale order, it is during this process that the relationships are established between the buying and the selling company. Findings show that the industrial buying behaviour of steelworks in Western Europe agrees well with the theory in this field. The buying process follows the steps in the buygrid model with only a few exceptions. The decision-making power lays in the intermediate level management, even though approval is required from upper level management. The most important factors affecting the buying behaviour are the relationship between the buyer and the seller, service-life and life cycle cost of the roll-line.
Acknowledgement

We have been able to conduct these studies and to write this report thanks to the help and advice of many people. First of all, we would like to express our thanks to our tutors Professor Magnus Odén and Director of Studies Lars-Ole Forsberg of Luleå University of Technology and Anneli Sundblom and Mats Johansson of SKF.

We would like to direct special thanks to Ingrid Brundin who helped and guided us during the metallurgical study.

Pekka Juuti helped us with the ultrasonic testing, Roger Björn shared his knowledge of steel and welding and Hans Kjellberg introduced us to the concept of strategic selling, all for which we are very grateful.

We must not forget to thank Patrik Costa, Ingo Wellmann, Martin Thorn, Tommy Rochhausen, Axel Gross, Anders Lövgren, Jorma Laine and Ari Numminen for their helpfulness.

Very many thanks go to Ingegerd Nilsson for all the help.

Finally we would like to thank all the people at the different steelworks, who wish to remain anonymous, who kindly received us and answered our questions.

Göteborg, August 2006

Erik Stenback-Lund    Henrik Nordenström
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1. Introduction

The continuous casting process stands for about 90 % of the steel currently produced worldwide. Casting rolls are vital parts in the production facilities of the continuous casting steelworks. The service life of casting rolls can become the limiting factor for efficient long run caster operation. Roll performance may also affect the quality of the steel.

SKF is the world's leading bearing supplier. The company has quite recently decided to go from selling components to become a knowledge-based company selling solutions. In line with this new strategy, SKF is since 2001 offering a complete continuous casting roll-line solution, called ConRo, including service and maintenance. As a new actor on the market, the company wishes to increase its knowledge both of continuous casting roll technology and of the market situation for this product.

This Master’s thesis consists of two independent studies: One metallurgical study of two continuous casting rolls and one industrial buying behaviour study for continuous casting roll-lines.
2. Metallurgical Study

2.1. Abstract

The first objective of this study was to investigate two different continuous casting rolls. The second objective was to evaluate the methods employed in the study.

The rolls were investigated using macro etching, optical microscopy, Vickers hardness testing, ultrasonic testing ICP-OES analysis of nickel and chromium content and carbon content analysis by wet chemical method. Delta ferrite content was also calculated theoretically using a Schaeffler – DeLong diagram and a semi-empirical model.

Both rolls consist of a steel tube with stainless martensitic steel weld overlays applied by submerged arc welding.

The weld overlaps are clearly the weakest points of the weld overlay. They are sensitive to corrosion attacks, mainly due to sensitisation.

The delta ferrite present in the welded overlay of both rolls is a preferential site for the corrosion attacks and the delta ferrite content depends primarily on the chemical composition of the weld overlay. The welding temperature may also have some influence on the delta ferrite content, but this has not been observed in this study.

Both rolls have similar surface hardness. Roll no. 2 has more generalized corrosion attacks than roll no. 1. This is due to a higher delta ferrite content in roll no. 2 than in roll no. 1.

The methods employed during the study proved to be adequate. In any future study, on condition that the visual inspection, diameter measurements, ultrasonic testing and surface hardness measurements show that all positions on the roll are similar, it will be sufficient to cut a bead and overlap sample from only one position.


2.2. Introduction

The continuous casting process stands for about 90% of the steel currently produced worldwide. Casting rolls are vital parts in the production facilities of the continuous casting steelworks. The service life of casting rolls can become the limiting factor for efficient long run caster operation. Roll performance may also affect the metallurgical quality of the steel.

The environment in a continuous caster is extremely harsh. Casting rolls are subjected to high temperatures and loads, as well as corrosive acids and abrasive wear. Many studies have been made to understand and prevent the causes of roll failure. The study made by McCann and Stevens [1] constitutes a fundamental piece of work. Handerhan and Hinkel [2] made a significant contribution to the understanding of the role of fracture mechanics in the design of continuous casting rolls. The problem of understanding the failure mechanisms of continuous casting rolls is very complex. There seem to be no ideal recipe for casting roll design. One must adapt to the specific conditions in each caster.

As a provider of casting rolls, SKF is interested in increasing its knowledge in this field, in order to improve the quality of their product. In this study two casting rolls will be investigated.
2.3. Objectives

The first objective of this study was to investigate two continuous casting rolls. The second objective was to evaluate the methods employed in the study.
2.4. Background

In this chapter a brief introduction to the continuous casting process will be given. The function and design of continuous casting rolls will be described. Special attention will be paid to the materials used. The complex problem of material failure in continuous casting rolls, with an emphasis on the different degradation mechanisms will also be discussed.

2.4.1. Functioning of a continuous casting machine

In the continuous casting process molten steel is transformed into long semi finished products of constant cross section on a continuous basis (Figure 2-1). This process is used to manufacture about 90% of all the steel currently produced worldwide [3].

![Schematic presentation of the continuous casting process](image)

**Figure 2-1** Schematic presentation of the continuous casting process [4].

In the continuous casting machine (CCM), molten metal is tapped into the ladle from furnaces. After undergoing any ladle treatments, such as alloying or degassing, the ladle is transported to the top of the casting machine. From the ladle, the hot metal is transferred to a holding bath called a tundish. The tundish holds enough metal to provide a continuous flow to the mould, even while exchanging ladles. The mould is water-cooled and oscillates vertically to prevent the metal sticking to the mould walls. Powder (flux) is also added to the metal in the mould to prevent sticking, and to trap any slag particles such as oxide particles or scale.

A thin layer of metal next to the mould walls solidifies before the metal section, now called a strand, exits the base of the mould into the cooling-chamber (also called spray-chamber). In the cooling-chamber the strand is supported by rolls and large quantities of water is sprayed on the strand in order to increase the rate of solidification and to cool the rolls. At this stage, the risk of breakout occurring is greatest. A breakout is when the solidified strand surface breaks and liquid steel leaks out.
Final solidification of the strand may take place after the strand has exited the cooling-chamber. The distance from where the centre of the strand is completely solid to the mould is called “metallurgical length”. Figure 2-1 shows a horizontal casting machine where the strand exits the mould vertically and the rolls gradually curve the strand towards the horizontal.

After exiting the cooling-chamber, the strand passes through straightening rolls (if cast on a horizontal machine) and withdrawal rolls. There may be a hot rolling stand after withdrawal, in order to take advantage of the metal's hot condition to pre-shape the final strand. Finally, the strand is cut into predetermined lengths by mechanical shears or by travelling oxyacetylene torches. These lengths have different names, for example slab or bloom, depending on the form of their cross-section. Figure 2-3 shows the most common types of continuously cast sections.
2.4.1.1. Caster Environment

The working conditions for casting rolls are extremely harsh and vary depending on the location within the caster. Slab casters require rolls to perform under loads up to 100 tons while in contact with a two 2 meter wide strand at 1000°C [2]. The position in the caster where rolls are most sensitive to cracking failure is where the strand changes its direction from vertical to horizontal. However, all rolls independent of its position, are to some extent exposed to elevated temperature, high cyclic stress / strain, non-steady state conditions, and corrosive and abrasive environments.

The environment varies significantly from one caster to another. Also, in the same caster, the working conditions are not constant over time. For instance, changing the production to another steel grade will require a change of mould powder, temperature, cooling water flow, casting speed and so on. Of course, this will change the working conditions for the casting rolls. This is one of the reasons why it is difficult to find an optimal solution for continuous casting roll design.

2.4.2. Casting Roll Design

*Casting rolls* are also called continuous casting rolls, caster rolls, support rolls or strand guide rolls. In this report they will be called casting rolls. They are located in the continuous casting machine after the mould, in the cooling chamber (cf. Figure 2-1). When the strand comes out of the mould it is solidified only on the surface. The casting rolls will support, guide and convey the strand through the cooling chamber. In a continuous casting machine there are usually between 350 and 750 rolls, B.D. Horn [7].

Rolls generally consist of a *roll body* or a *roll mantle* and a *cladding*. A roll body consists of the roll itself and an axle together as a one solid piece. The axle is mounted on bearings guarded in housings, cf. Figure 2-4a. The roll body may be equipped with a cooling system, as described below, cf. Figure 2-5. This design is used in the lower segment.

Regarding roll mantles, there are two different designs. The first variant, used in the lower segment, consists of a tube mounted and fixed on an axle with a wedge, cf. Figure 2-4b. As in the case of the roll body design, the axle is mounted on bearings guarded in housings and can be
equipped with a cooling system. The second roll mantle alternative is used in the top segment and consists of a tube mounted on an axle with bearings as shown in Figure 2-4c. This design does not benefit from any other cooling than external cooling and as the axle is fixed it is only the mantle that turns. The cladding is a material that can be applied on the roll surface in order to increase corrosion and wear resistance. Different kinds of roll body roll mantle and cladding materials will be further discussed in the paragraphs 2.4.2.1 and 2.4.2.2.

In the cooling chamber, nozzles spray water to cool the strand, but also to cool the caster rolls. This is called the external, or secondary cooling. The rolls sometimes also have internal cooling (also called primary cooling). This cooling may be of various types: centre bore, peripheral bore (also called revolver cooling) and spiral bore cooling (cf. Figure 2-5). The centre bore cooling is the least efficient, but also the cheapest to manufacture. With the spiral bore cooling and the peripheral bore cooling the thermal resistance of the rolls is improved. However, a very good control and maintenance of the water-cooling system is necessary to avoid failure. This will be discussed more extensively in section 2.4.3.1.

Figure 2-4 schematic views of the different types of roll design: a) Roll body, b) Roll mantle with rotating axle and c) Roll mantle with fixed axle.

Figure 2-5 Types of internal roll cooling [7].
The cooling power of the internal cooling still remains limited; external cooling may account for as much as 60% of the total cooling effect [1]. The cooling system also often comprises cooling jackets on the housings to avoid over-heating of the bearings.

In order to lubricate the bearings, grease is pumped continuously through the housings. A continuous casting machine consumes approximately 70 tonnes of grease per year. Grease polluting the cooling system water is a big problem. It leads to clogged water filters and spray nozzles, thus resulting in insufficient cooling of the strand and the rolls. SKF is today the only company to offer completely sealed housings, therefore eliminating the need of relubrication.

In the casting machine, the rolls are assembled in roll-lines as shown in Figure 2-6.

![Figure 2-6](image)

**Figure 2-6** A roll-line with three rolls (split roll configuration) and six bearing housings.

According to B.D. Horn [7], roll-lines are generally described by the bearing support configuration and the type of internal cooling. There are two types of bearing configurations: the old *wide body configuration* and the new *split roll configuration*. These configurations are shown in Figure 2-7. In order to support the strand better, to avoid inter-roll bulging (cf. Figure 2-8 a), the trend today goes towards small diameter rolls and closely spaced roll-lines. Smaller roll diameters leads to increased strand bulging due to roll deflection (cf. Figure 2-8 b). To counter this problem the split roll configuration is increasingly used. This problem is treated more extensively in paragraph Mechanical Stresses, chapter 2.4.3.1.

![Figure 2-7](image)

**Figure 2-7** Layout of caster rolls [7].
The roll-lines are mounted in segments (cf. Figure 2-9). Single rolls are rarely changed. Entire segments are taken out and replaced with a new one when rolls have completed there service-time. Mounting rolls in segments makes the adjustment of roll-gap and roll alignment easier.

In some cases, grooves are machined in the surface of the caster rolls (cf. Figure 2-10). Grooves accommodate the stress generated by the thermal expansion. This reduces / eliminates the cracking due to thermal fatigue [8]. However, at the same time these grooves may be preferential site for crack initiation, cf. Figure 2-11. S. Malmström [9] reported of a 40% reduction of roll material consumption at Case 3 after the steelworks started to use caster rolls with grooves.
Furthermore, grooves have the advantage of diminishing the contact surface with the strand, and thus reducing the heat transfer from the strand to the roll. As a consequence of this, the heat transfer from the rolls to the bearings will be reduced. This is advantageous because the grease used for lubricating the bearings is usually quite heat sensitive. Additionally, grooves increase the effect of external cooling as the water gets in contact with a larger roll surface. In some cases mould flux has been reported to clog the grooves, thus reducing the extra cooling effect [10]. Whether to use grooves or not is a complex question that needs to be decided individually for each casting machine.

Figure 2-11 Crack at the bottom of a groove due to thermal fatigue [9].

Figure 2-12 shows a typical strand layout. The first rolls, after the mould, are called top segment rolls, top zone rolls or segment 0 rolls. To give a larger contact surface, hence reducing the risk of breakout these rolls have a small diameter and are closely spaced. Since they do not have to support any heavy mechanical load, their small diameter is not a problem. This close to the mould the temperature of the strand is high and the pH is low due to the mould flux. The rolls are cooled by intensive external cooling. No internal cooling is necessary.

Further down the strand come the bender rolls, the bow, the unbending rolls and the withdrawal-straightener rolls. The diameter of the roll increases down the strand, as the steel solidifies and the mechanical load increases. The unbending rolls are the most solicited mechanically and they are particularly thick.

Rolls may be driven or idler (i.e. non-driven). Top-zone rolls are never driven, because the strand is too fragile at this point to withstand the stress from a driven roller without a breakout. In the lower segments there are both driven and idler rolls.
2.4.2.1. Roll body and mantle materials

According to [2], a good roll body or mantle material should have the following properties:

- Good high temperature yield strength
- Good temper resistance and thermal stability
- High fracture toughness and a low ductile-brittle transition temperature
- Good weldability
- High forging integrity

Thus the roll body / mantle material will be able to withstand thermal and mechanical bending stresses, thermal fatigue and residual stresses. Commonly, forged tool steels are used for this purpose, e.g. DIN21CrMoV5 -11 [11]. Typically the carbon content of the steel is between 0.13 and 0.40 % C [2]. Often different roll body / mantle materials are used in the different sections. In the top segment low carbon contents are used to avoid a too severe corrosion. In lower segments higher carbon contents are used for increase mechanical strength.

Usually the corrosion is not a very big problem. The roll body / mantle will be corroded, but other components usually tend to fail before this corrosion becomes too important. However, in some cases non-cladded rolls are used. For example T.J. Nugent et al. [12] describe the use of centrifugally cast specially heat treated martensitic stainless steel alloy rolls in the top zone and as bender rolls. This solution was chosen to counter severe corrosion problems in the roll mantle material previously used.
2.4.2.2. Cladding

The selection of cladding material is generally based on the following considerations [13]:

- Pit corrosion resistance
- Thermal fatigue cracking resistance
- Corrosion cracking resistance
- Wear resistance
- Weldability
- Elevated temperature strength
- Elevated temperature microstructure stability

In general, weld materials are selected by relatively simple tests at the roll-supplier and by long-term trials on the casting machine concerned [14]. A standardized test procedure using Gleeble tests, FEM-analysis and metallurgical analysis (optical microscope, SEM, EDS, WDS, micro probe, micro hardness) has also been developed [15, 16], however this procedure does not take into account the influence of corrosion. The most common cladding material used today is stainless martensitic steel [11], because it combines the above-mentioned properties with a reasonable price. The cladding is usually applied by submerged arc welding (SAW). This technique will be described in the paragraph 2.4.2.3. Some examples of martensitic steels for claddings are given in Table 2-1.

Table 2-1 Chemical compositions of some martensitic stainless steels used as cladding material, applied by SAW.

<table>
<thead>
<tr>
<th>Name</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>V</th>
<th>W</th>
<th>Nb</th>
<th>Cu</th>
<th>N</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI 423 [17]</td>
<td>0.12</td>
<td>1.0</td>
<td>0.43</td>
<td>11.8</td>
<td>2.63</td>
<td>1.18</td>
<td>0.18</td>
<td>0.03</td>
<td>0.17</td>
<td>0.020</td>
<td>0.017</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>W 240 [16]</td>
<td>0.08</td>
<td></td>
<td>13.3</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Super KBS [18]</td>
<td>0.16</td>
<td></td>
<td>12.9</td>
<td>0.1</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sometimes a buffer layer is applied before applying the actual cladding. This is done to obtain optimal adherence of the cladding and in some cases also to avoid corrosion between the cladding and the base material. In the latter case the buffer layer has a high content of Cr. This is done in order to obtain a final composition high on Cr more rapidly. Then finishing layers are applied which are not as rich in Cr but might contain other alloying elements such as Ni, Nb, V and Mo.

During service, rolls are taken out and their surface machined to remove cracks and irregularities. Then they are put back into service. The gap between the rolls is adjusted to obtain the desired thickness of the strand. An incorrect roll gap distance will lead to bad slab quality. Malmström [9] mentions a ± 0.5 mm gap tolerance. When the cladding becomes too thin it is machined a last time, then a new cladding layer is applied.

New Claddings

Current approaches to new roll coatings are focused on retarding the rate of thermally and mechanically induced fatigue / corrosion cracks to increase wear resistance at high temperatures.

New martensitic stainless steel welding materials are being developed. Some examples are given in Table 2-2. The ultra low carbon content will improve the thermal fatigue properties of the material even at high delta ferrite numbers (cf. 2.4.2.3 Delta Ferrite) [17]. Perhaps more importantly, the carbon content is kept low to reduce the problem with sensitisation (cf. paragraph 2.4.3.4) [Ibid]. For the same reason, strong carbide formers, other than Cr, like V, W,
Neb and Ti, may be added [7]. N is added to compensate for the lack of carbon and provide interstitial strengthening. Nitrogen will also form nitrides like TiN and carbonitrides like V(C, N). This will improve the wear resistance. Mo was added to provide substitutional strengthening and to improve the corrosion resistance [17].

### Table 2-2: New (mainly) martensitic stainless steels for SAW [17].

<table>
<thead>
<tr>
<th>Name</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>V</th>
<th>W</th>
<th>N</th>
<th>P</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alloy 1</td>
<td>0.05</td>
<td>0.75</td>
<td>0.48</td>
<td>12.2</td>
<td>5.2</td>
<td>3.2</td>
<td>0.56</td>
<td>0.57</td>
<td>0.025</td>
<td>0.021</td>
<td>0.007</td>
</tr>
<tr>
<td>Alloy 2</td>
<td>0.05</td>
<td>0.73</td>
<td>0.45</td>
<td>12.5</td>
<td>4.3</td>
<td>2.0</td>
<td>0.60</td>
<td>0.59</td>
<td>0.023</td>
<td>0.017</td>
<td>0.006</td>
</tr>
<tr>
<td>Alloy 3</td>
<td>0.03</td>
<td>1.8</td>
<td>0.5</td>
<td>11.9</td>
<td>4.1</td>
<td>1.7</td>
<td>0.80</td>
<td>0.70</td>
<td>0.090</td>
<td>0.010</td>
<td>0.007</td>
</tr>
</tbody>
</table>

Tests with laser deposited nickel and stainless alloys and chemically hardened HVOF (High Velocity Oxygen Fuel) deposited WC-Co coatings have been performed with good results [11]. Other materials and welding processes have also been evaluated. Some examples are: plasma transferred arc deposited cobalt based alloys [19], nickel-based alloys [10] and Cr3C2-NiCr detonation spray coatings [20].

The breakouts, mentioned in paragraph 2.4.1.1 Non Steady State Condition, are a limiting factor in the choice of cladding material. A breakout will damage any cladding material. With poor process control breakouts will occur frequently and thus expensive high performance cladding materials will not be cost efficient.

#### 2.4.2.3. Submerged Arc Welding

As mentioned above, submerged arc welding is probably the most common technique for applying cladding to a roll surface. In the process, successive beads of overlay weld are placed side-by-side until the entire roll face is covered (cf. Figure 2-13).

![Figure 2-13](image_url) Photo of a roll taken out of service. The roll was cladded with submerged arc welding. The areas where the beads overlap are seen as dark lines.

The process can be fully automated. Figure 2-14 shows a schematic picture of the submerged arc welding technique. The welding material comes from the electrode wire that is continuously fed. A metal powder, also called flux, covers the arc and the molten metal. This avoids the risk of air entrainment or severe sputter [21]. The electrode oscillates back and forth creating a molten bead (cf. Figure 2-15). Some alloys, like nickel, are added via the flux. Others, like chromium, are added via the electrode. Adding nitrogen to the weld has been problematic, but [17] reports of successfully using a wire electrode cored with nitrogen bearing alloy powder.
Submerged arc welding can be performed with single wire or twin arc (two wires). With the latter, the deposition rate can be as high as 18 kg/h. Finally, strip cladding (electrode in form of a strip) with a strip width of 30 to 100 mm can be used (cf. Figure 2-16). The larger width is used for big diameter rolls. This gives a deposition rate of up to 20 kg/h [24].

Before welding, the roll must be preheated to 250-300°C. Otherwise the first layer, which has high carbon and low chromium content, due to dilution, will quickly build up martensite that can initiate cracks [24]. The heat treatment will also eliminate any moisture on the roll. After welding, the roll must be heat treated again, to temper the martensite in the cladding. This lowers the hardness and increases the toughness of the cladding. It also makes the cladding more
homogeneous in terms of hardness. The tempering is done at temperature of about 550°C for approximately 8 hours.

*Delta Ferrite*

Delta ferrite is supposedly the first phase to form when the liquid steel solidifies. With further cooling the austenite starts to grow in both the liquid and in the previously formed delta ferrite. At the end of solidification the weld metal enters a ferrite - austenite region or a one-phase austenitic region depending on cooling rate and chemical composition. Upon further cooling, austenite is transformed into martensite and the final microstructure is fully martensitic or martensitic with primary delta ferrite. Additional weld passes will affect the microstructure. If a weld is heated to the two-phase ferrite – austenite region, the primary delta ferrite will transform into an intergranular delta ferrite and on subsequent cooling the austenite will transform into martensite. On the contrary, if a weld is heated to the one-phase austenitic region, the primary delta ferrite will transform completely or partially into austenite. On subsequent cooling the austenite will transform into martensite and the final microstructure will be completely martensitic or martensitic with only small isolated islands of delta ferrite. Accordingly, a fully martensitic microstructure is favoured by alloying elements such as Ni, Cu and Co that are known to stabilise the austenitic region at lower temperatures [26].

It is recommended to keep the percentage of delta ferrite in the martensitic matrix below 10% [13]. About 5% of delta ferrite only augments the toughness, because the ferrite is ductile. However, the ferrite is not corrosion resistant. With 10% delta ferrite an interconnected network of delta ferrite is formed. This will radically diminish the corrosion resistance of the cladding. Chromium is a ferrite former and nickel is an austenite former [27]. The chromium and nickel equivalents are calculated from the composition of the metal and so the percentage of delta ferrite can be estimated using a Schaeffler Delong diagram (Figure 2-17).

![Figure 2-17 Schaeffler Delong diagram. The black lines represent the phase field boundaries, while the grey lines indicate the region where either the Mf point (lower line) or both the Mf and Ms points (upper line) lie above ambient temperature. Between them transformation to martensite is only partial [28].](image-url)
Welding Defects

The presence of pores and slag inclusions in the weld are the two most common defects when applying a surface layer on casting rolls. There are two types of pores; pores at the surface of the weld and pores within the weld. Surface pores are formed when gas, predominantly hydrogen, is emitted during the solidification of the weld and trapped due to rapid cooling. Rapid cooling can be due to a high welding speed or to moisture present on the roll or in the weld flux. By lowering the weld speed and by preheating the roll in order to eliminate moisture, the formation of pores can be avoided. If the weld flux contains moisture, pores can also be formed between the weld and the slag-bead [9].

If the distance between two weld-beads is too great, gas derived from the slag between the beads is trapped within the weld. To avoid this one must see too that the weld-beads properly joined during welding.

Slag inclusions are rarely observed and will occur if the slag, which adheres to the weld, is left in place when applying a new layer. Usually, the slag does not adhere to the weld but this can be the case if the surface gets too hot or if the welding parameters are not adequately set. The presence of slag inclusions can be avoided by assuring a proper slag removal before applying a new layer.

2.4.3. Casting Roll Degradation

Insufficient maintenance may be the most common cause for roll failure. For example, a bearing failure due to bad maintenance will lead to a blocked roll. The roll surface will then suffer excessive abrasive wear. Misaligned segments will lead to an incorrect load situation of the rolls which results in early roll-line failure. Insufficient process control leads to frequent breakouts. When they occur the roll-lines are severely damaged and must be taken out of service. To avoid catastrophic roll failure (cf. Figure 2-18), rolls are usually removed after a certain time in service. The time in service is based on historical data on the performance of each roll in its position.

![Figure 2-18](image)

Figure 2-18 Catastrophic roll failure due to fatigue. The crack causing the failure initiated at the bottom of one of the grooves and propagated towards the centre of the roll [9].

The environment in a continuous caster is extremely harsh and, even without maintenance and process control problems; the life of continuous casting rolls is limited. All rolls are, to some extent, exposed to elevated temperature, high cyclic stress / strain, non-steady state conditions, and corrosive and abrasive environments.
Except for degradation related to bad maintenance or breakouts, the main reasons for roll withdrawal are [11]:

- Excessive surface wear beyond the required roll gap tolerance
- Surface degradation due to excessive thermal fatigue cracking
- Permanent roller bending beyond the required roll tolerance
- Catastrophic roller failure due to brittle fracture or fully plastic collapse
- Corrosion damage

These failure modes are the results of a simultaneous action of various factors that will be described in the following paragraphs.

2.4.3.1. Stresses

According to Handerhan and Hinkel [2], the caster rolls will be subjected to the following types of stresses:

- **Cyclic thermal stresses**, due to repeated heating and cooling as the roll alternates contact with the hot strand and external cooling sources.
- **Thermal bending stresses**, during stops when one side of the roll is heated by the strand and the other cooled by the external cooling.
- **Mechanical bending stresses**, due to the weight of the strand, bulging from ferrostatic pressure, strand straightening and when pulling through bulged strands or strands with breakouts etc.
- **Residual stresses** associated with the roll fabrication process, e.g. the weld cladding, the heat treatment, the forging, etc.

![Figure 2-19 Forces acting on a casting roll [7]. The force resulting of strand bending and unbending, in the corresponding zones, should not be neglected.](image)

**Thermal Stresses**

During service, the rolls will be turning most of the time. In this report it is called *steady state*. Occasionally the strand will be stopped, for example during tundish or tube change, or due to a breakout. The hot strand will be resting on the rolls without them turning. This is called *non-steady state*.

A roll is heated by the hot strand and cooled by the internal and external cooling. This leads to *thermal gradients* within the roll. The severity of temperature and thermal gradients depends on
roller cooling (varies with position in the caster), caster speed (i.e. steady and non-steady state) and required cooling rate of the strand. Mechanical properties, such as Young's modulus (E) and yield strength (σ_Y) decrease with increasing temperature. Thermal stresses are greatest during non steady-state conditions associated with reduced casting speed and strand stoppages [1].

The thermal gradients in the roll will lead to thermal bending into the strand (i.e. the slab) as shown in Figure 2-19. It has been observed that in the bow, during stoppage, the solidified shell of the hot strand is not strong enough to resist the thermal bending of the rolls. [14]. The following expression is used to estimate thermal stresses in the elastic region:

\[ \sigma = \alpha \ E \Delta T \]  

Equation 2-1

Where:
- \( \sigma \) = thermal stress
- \( \alpha \) = coefficient of thermal expansion
- \( E \) = Young's modulus
- \( \Delta T \) = maximum temperature - minimum temperature

A low coefficient of thermal expansion and a low Young's modulus will reduce the thermal stress. However, these parameters are not easily modified without changing to a mechanically less resistant material. The thermal stress also depends on \( \Delta T \). Consequently, an efficient internal cooling will diminish the thermal stress.

Peripheral and spiral bore cooling are more efficient than central bore cooling, since their cooling source is closer to the surface. An efficient internal cooling system can limit the temperature in the hot part of the roll and reduce the thermal gradients in the roll. However, if the cooling system is blocked, a roll with a central bore cooling will be more resistant mechanically to thermal stresses, than a roll with central or spiral bore cooling. This is due to the number and location of the bores. Close to the surface of the roll, the stress will be greater. Consequently, a bore located close to the surface will diminish the mechanical strength of the roll more than a central bore. Of course, the greater the number of bores, the weaker the roll.

Common reasons for cooling system failure are deposits, due to polluted cooling water. If the water in the internal cooling system reaches the boiling temperature, the cooling will be much impaired, since the cooling power of vaporized water is much inferior to that of liquid water.

During steady state operation, the temperature of the roll surface in contact with the strand can be as high as 426°C (800 F) [29] or even 590°C [2]. The opposite side is much cooler, below 100°C, as a result of external and internal cooling. On a roll, the hot surface material in contact with the strand, will try to expand, but will be hindered by the cooler material further below the surface (cf. Figure 2-20). The surface will be under compressive stress and there will be a very small plastic deformation. As the roll continues to turn, the hot material will be cooled by internal and external cooling, and try to contract. This will not be possible, since it has been deformed plastically. Instead tensile stresses will be created. These cyclic thermal stresses, thermal fatigue that is, leads to crack initiation followed by crack propagation.
Thermal fatigue is classified as a low cycle fatigue with normally about $10^4$ to $10^5$ cycles to rupture [30]. Thermal fatigue is responsible for thermal cracking of the roll surface, cf. Figure 2-21. The surface will be degraded - rough - leading to bad strand quality. Eventually the propagation of thermal cracks may lead to catastrophic failure: the roll breaks into pieces.

In non-steady state condition, when the strand is blocked, the temperature in the side of the roll that is in contact with the strand will rise. It can be as high as 650°C [2] - or even 900°C [9]. The opposite side will be considerably cooler, often below 100°C (cf. Figure 2-22). This will lead to a thermal dilatation on the hot side and a contraction on the cool side. The result is plastic deformation - thermal bending. Of course, this situation may also lead to thermal crack initiation and accelerate crack propagation.
Figure 2-22 Roll temperature during strand stoppage (one revolution). The temperature was measured with thermocouples at four different depths below the roll surface [14].

**Mechanical Stresses**

There are three types of mechanical stresses in the rolls: Bending stresses from the weight of the strand (cf. Figure 2-19); bending stresses from strand bending and unbending (in the corresponding zones - cf. paragraph 2.4.2 and Figure 2-12); and stresses from the strand bulging forces due produced by the ferrostatic pressure in the solidifying steel (cf. Figure 2-19) [2]. Bulging stresses due to the ferrostatic pressure increases as the strand approaches the end of the strand guide area [1].

If the roll is supposed to be a solid cylinder, the resultant *elastic stress* and *deformation* can be roughly estimated with the following expression:

\[ \sigma = \frac{Mr}{I} \]  

Equation 2-2

Where: \( \sigma \) = mechanical stress  
\( M \) = applied bending moment  
\( r \) = radial distance from the roll centreline  
\( I \) = moment of inertia, defined as follows:

\[ I = \frac{\pi D^4}{32} \]  

Equation 2-3

Where: \( D \) = diameter of the roll

Using the two equations above, the maximum fibre bending stress at the roll surface can be calculated, where \( r = D/2 \):
The elastic deflection of the roll can also be calculated:

\[
\delta_m = k \frac{32 w L^4}{\pi D^5}
\]

Where:

- \( k \) = constant
- \( w \) = the sum of external forces per length unit
- \( L \) = the distance between support bearings

Even though damage of rolls occurs when there is a plastic deformation, these equations work as estimations. The following observations can be made:

- The stress decreases with the roll diameter to the power of three.
- The roll deflection increases with the distance between support bearings to the power of four and decreases with the roll diameter to the power of four.

This shows us that the split roll configuration shown in Figure 2-7 is efficient to avoid bending, especially if the rolls have a small diameter.

### 2.4.3.2. Residual Stresses

Residual stresses remaining in the roll body / mantle material have little effect on roll performance. Still, residual stresses remaining in the cladding after welding and heat treatment have an effect on crack initiation and propagation. Compressive residual stresses in the surface are desirable as they provide increased resistance to crack initiation. Wolf and Stucker [31] reports of compressive stresses at the surface of a roll with 12\% Cr martensitic stainless steel weld cladding. However, in a zone a short distance further below the surface, the compressive stresses turn into tensile stresses (cf. Figure 2-23). These tensile stresses are known to have accelerating effect on crack propagation.

![Figure 2-23 Residual stress in the cladding after heat treatment.](image-url)
2.4.3.3. Wear

**Abrasive Wear**

In order to secure a high slab quality, tolerances regarding roll alignment in a caster machine are quite severe and can be as low as 0.13 mm [12]. Abrasive wear of the roll surface is caused by slag, scale and mineral deposits. Additionally, elevated temperatures and corrosion processes have an increasing effect on wear rate.

**Mechanical smearing and deformation of surface**

The elevated temperature in combination with high contact pressure can cause plastic deformation of the roll surface. During contact, asperities on the strand and roll surface bond temporarily. As the roll turns this contact will be broken, leading to surface discontinuities, this is detrimental for slab quality.

2.4.3.4. Sensitisation

*Sensitisation* is the precipitation of chromium carbides, mainly of the type \( \text{Cr}_2\text{C}_6 \) [32], at the grain boundaries (cf. Figure 2-24). This occurs at high temperatures and the carbides form a brittle network that is sensitive to rapid cracking when subjected to thermal shock loads. Also, the chrome-depleted zones are more susceptible to corrosion (cf. paragraph 2.4.4.1). In martensitic stainless steels, sensitisation takes place when the material is subjected to temperatures in the range of 500 - 650°C [33].

Because of the heat produced when welding, welded steels are often susceptible to sensitisation especially in the heat-affected zone (HAZ). Sensitisation can usually be avoided by lowering the carbon content of the steel and by alloying with elements that form carbides more readily than chrome such as Titanium (Ti) and Niobium (Nb) [34]. When applying the cladding by strip arc welding, the corrosion sensitive inter-bead areas can be reduced by using a wider strip [12].

![Figure 2-24](image_url) Representation of sensitisation occurring due to welding [35].

2.4.4. Corrosion

The *fatigue resistance* of casting rolls is considerably decreased due to the simultaneous action of cyclic stress and corrosion attacks. This phenomenon is called *corrosion fatigue*. It is often observed in water, salt water and acid solutions. Normal fatigue cracks are typically transgranular while corrosion fatigue cracks may be intergranular, transgranular or a combination of both. When it comes to corrosion fatigue, *pitting* is frequently the source of crack initiation. Multiple crack initiation and coalescence of existing cracks is an important feature of corrosion fatigue [36, 37].

The large amount of cooling water, the elevated temperature and the presence of mould flux makes the upper segment a very corrosive environment. Calcium fluoride (CaF\(_2\)) is a common...
mould flux component and is insoluble in water. At high temperatures though, it can react with water to give hydro fluoric acid [38].

\[ \text{CaF}_2 + 2\text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + 2\text{HF(aq.)} \]

This hydro fluoric acid is the major contributor to this corrosive environment. Due to the presence of mould flux, corrosion of the rolls is more pronounced in the upper segments [12].

2.4.4.1. Grain boundary corrosion

Corrosion can be the result of sensitisation that takes place at high temperatures. Zones adjacent to these grain boundaries will be drained on Cr and thus more susceptible to corrosion attacks, cf. Figure 2-24. Zones, locally affected by corrosion, constitute favourable sites for crack initiation and propagation. This phenomenon has been observed in the heat-affected zones adjacent to interbead weld areas. [13].

2.4.4.2. Pitting Corrosion

Pitting corrosion are local corrosion attacks. It occurs where the protective chromium oxide layer has been damaged. It is enhanced by the presence of chloride ions. The groove, usually machined in the cladding with purpose to ease thermal stresses, can act as an initiation site for cracks. According to [8], these types of cracks can be induced by the action of cooling-water containing chloride ions. Sometimes, the cooling water contains calcium compounds that can deposit and partially cover the bottom of the grooves. In this case, there is a risk that chloride ions accumulate under the calcium deposits and even more increases the risk of pitting.
2.5. Method

Two different rolls were investigated. As mentioned in paragraph 2.2, they are made of different materials. Both rolls consist of a rotating roll mantle on a fixed axle, as illustrated in Figure 2-4 c. On the mantle, a cladding layer is welded with submerged arc welding.

The rolls were designated 1 and 2. The ends of the rolls were named A and B and the middle was named M. Two positions on the roll circumference, separated by 90°, were called II and I respectively. This is illustrated in Figure 2-25.

![Figure 2-25 Schematic of the rolls 1 and 2.](image)

Specifications of roll base material and welding overlay material are presented in Table 2-3. Chemical composition of the welding overlay and base materials are shown in Table 2-3 and Table 2-4 respectively.

<table>
<thead>
<tr>
<th>Roll no.</th>
<th>Base material</th>
<th>Weld Overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Material |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |               |
Table 2-5 Chemical composition of the roll base materials

<table>
<thead>
<tr>
<th>Material</th>
<th>1.0570</th>
<th>Max 0.22</th>
<th>Max 0.55</th>
<th>Max 1.60</th>
<th>Max 0.040</th>
<th>Max 0.040</th>
<th>-</th>
<th>-</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6582</td>
<td>0.32</td>
<td>–</td>
<td>0.39</td>
<td>Max 0.40</td>
<td>0.50</td>
<td>–</td>
<td>0.80</td>
<td>Max 0.035</td>
<td>Max 0.035</td>
</tr>
<tr>
<td>1.30</td>
<td>–</td>
<td>1.70</td>
<td>0.15</td>
<td>–</td>
<td>0.30</td>
<td>1.30</td>
<td>–</td>
<td>1.70</td>
<td>0.15</td>
</tr>
</tbody>
</table>

2.5.1. Size Measurement and Visual Inspection

In order to see if the rolls had been worn during service, their diameter was measured 5 times each at position A, M and B (cf. Figure 2-25). This was done with a slide calliper of the brand KANON having a precision of 1/50 mm. The length of the rolls and the distance between the weld overlaps was measured with a ruler. The thickness of the goods was also measured with a calliper. The roles were observed and photographed with a Konica Minolta Dimage G530. Then the rolls were finely ground with sand paper grade 800 to remove oxidation and asperities and photographed with a Kappa DVM macro camera.

2.5.2. Ultrasonic Testing

The roll surfaces were finely ground to remove oxidation and roughness. Then the rolls were tested with ultrasonic testing using the pulse-echo method with an A-scan presentation. Both longitudinal and shear waves were used with frequencies of 4, 5 10 and 12 MHz. The pulse repetition frequencies used were 250, 500 and 1000 Hz. The gain was set for flat-bottom holes (FBH). The ultrasonic instrument used was a Krautkrämer-Branson USIP 12. Various probes of the brands Krautkrämer and Parameterics were used.

2.5.3. Surface Hardness

The hardness of each roll was measured at the positions A, M and B as indicated in Figure 2-25. The measurements were made in the welding beads, except for two series that were made in the overlap areas (cf. Figure 2-13).

Prior to the measurements the areas where they would be made were finely ground with SiC-paper down to grade 800, in order to remove oxides and asperities. At each position, a minimum of 10 measurements were made. In order to avoid the influence of stresses induced by an earlier indentation, the measurements were made with a distance of at least 2 mm.

The indentations were made in the surfaces that were not visually affected by corrosion. However, in the overlap zone of roll no. 2, this was not possible since the whole surface was affected and measurements had to be made in the attacked surface.

For the measurements a handheld Krautkrämer Branson Microdur hardness tester was used. The hardness was measured in HRC but was later on converted to HV according to the ASTM E140 – 97 standards.
2.5.4. Sample Preparation

The visual inspection (cf. paragraph 2.6.1 and 2.7.1) showed no difference between the positions A, M and B on each roll. Nor did the diameter measurements, the ultrasonic testing or the surface hardness measurements indicate any difference within the three positions (cf. paragraphs 2.6.1, 2.6.3.1, 2.7.1 and 2.6.2). Therefore samples were only cut from the positions A and M. The position B was assumed to have similar properties to position A.

Samples were cut at the positions AI, AII, MI and MII (cf. Figure 2-26). At each position, two samples were cut: one from the weld bead and one from the weld overlap. Hence a total of eight samples were sectioned from each roll.

![Figure 2-26](image)

Figure 2-26 Schematic of the rolls 1 and 2 and the samples taken out for measurements of chemical composition, and hardness.

2.5.5. Hardness Profile

As described in the previous paragraph, one weld overlap and one weld bead sample were cut from each of the positions AI, AII, MI and MII, at each roll.

![Figure 2-27](image)

Figure 2-27 Schematic of samples sectioned from the rolls for hardness testing, chemical analysis and metallographic study.

Each sample was mounted in Bakelite. The samples were then ground in order to make sure that they were plane and to remove any thermally affected material created by previous cutting operations. The weld bead samples were mounted so that the cross section corresponding to the XY-plane could be studied (cf. Figure 2-26). The weld overlap samples were mounted so that the cross section corresponding to the YZ-plane could be studied (cf. Figure 2-26). The grinding was carried out on a Struers Abraplan. Then, the specimens were cleaned and polished on a Struers
Planopol - 2. The diamond suspension used was Aka-Mono + 3 μm and 9 μm, the lubricant was Aka-Lube Clear +. The different grinding and polishing steps are described in Table 2-6.

Table 2-6 | Schematic of the sample preparation process for hardness measuring

<table>
<thead>
<tr>
<th>Step</th>
<th>Operation</th>
<th>Rotating disk</th>
<th>Time</th>
<th>Abrasive media and Lubricant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Grinding</td>
<td>Stone</td>
<td>30 s-</td>
<td>Water</td>
</tr>
<tr>
<td>2</td>
<td>Cleaning with cold water and detergent.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Polishing</td>
<td>Cameo Disk</td>
<td>3 min</td>
<td>Diamond suspension 9 μm and lubricant</td>
</tr>
<tr>
<td>4</td>
<td>Cleaning with cold water and detergent, then ethanol.</td>
<td>Dried with compressed air.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Polishing</td>
<td>Struers MD Plus</td>
<td>5 min</td>
<td>Diamond suspension 3 μm and lubricant</td>
</tr>
<tr>
<td>6</td>
<td>Cleaning with cold water and detergent, then ethanol.</td>
<td>Dried with compressed air.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Hardness Measurement**

The hardness was measured in Vickers with the indentation load set to 1 kg and the time 15 seconds. The hardness tester used was a Zwick 3202. Indentations were made at different positions in order to obtain the hardness profile in the directions X, Y, Z as indicated in Figure 2-27.

The two diagonals of the indentation mark were measured and their arithmetic mean value was used to calculate the hardness as shown in Equation 5-6.

\[
HV = 0.1891 \frac{F}{d^2}
\]

Equation 2-6

Where: HV = Vickers Hardness

\[F = \text{the applied force} = 1 \text{ kg} \times 9.82 \text{ N/kg} = 9.82 \text{ N}\]

\[d = \text{arithmetic mean value of the two diagonals of the indentation}\]

**2.5.6. Chemical Composition**

**2.5.6.1. Nickel and Chromium Profile by ICP-OES Analysis**

Four samples (AI, MI, AII, MII) from each of the two rolls were used for determining the chromium and nickel content in three dimensions (Figure 2-26).

For the chromium and nickel content along the y-axis, lines were drawn every one millimetre (cf. Figure 2-28). For every line, holes were drilled and the borings collected with a magnet and put in a plastic bag until a minimum quantity of 30 mg was obtained. The minimum quantity necessary to obtain a statistically reliable result from the ICP-OES (Inductively Coupled Plasma – Optical Emission Spectroscopy) analysis was 15 mg. The holes were drilled with a 1.0 mm diameter bit to a depth of max 3.0 mm. The 1.0 mm bit was used, because a thicker bit would not have given the same precision. The depth of the holes, 3.0 mm, was chosen to obtain a sufficient amount of borings from an almost constant depth below the roll surface. Before beginning to drill a new line of holes, the sample and the equipment were carefully cleaned with alcohol so as not to mix borings from different depths below the roll surface.
Figure 2-28 Cross section of a sample with holes drilled to obtain borings for the ICP-OES analysis. The sample was etched after the holes were drilled. The border between the base material and the weld overlay is clearly visible as a bright line.

For determining the chemical composition along the x-axis, holes were drilled in the roll surface in the middle of the weld-bead and at the weld overlap (cf. Figure 2-29). To obtain a sufficient amount of borings from the same position at the surface, a 2.0 mm diameter bit was used, instead of a 1.0 mm bit. The depth of the holes, 2.0 mm, was chosen arbitrarily to obtain a sufficient amount of borings without collecting these from too far below the roll surface.

Figure 2-29 Samples with holes drilled in the roll surface to obtain borings for the ICP-OES analysis from the centre of the weld bead and from the weld overlap.

Samples from position I and II (cf. Figure 2-26) were used to obtain information about possible variations in the chemical composition along the z-axis.

2.5.6.2. Surface Carbon Content Analysis by Wet Chemical Method

The carbon content at the surface was measured by wet chemical method at the same positions (AI, MI, AII, MII) as the ICP-OES analysis was done.
2.5.6.3. Chemical Composition Calculations with Semi-Empirical Model

SKF has developed a semi-empirical model for predicting the chemical composition of a weld overlay taking into consideration the mixing of the material from the electrode with the underlying material. The model gives the content of the different alloying elements as a function of the depth below the surface of the roll.

This model gives the chromium and nickel profiles shown in Figure 2-37 and Figure 2-40 for roll no. 1, and Figure 2-38 and Figure 2-41 for roll no. 2.

2.5.7. Macrostructure

The samples used for determining the chemical composition were also etched in order to distinguish the number and position of the welded layers. The XY-plane and the YZ-plane (cf. Figure 2-27) were examined. The etchant used was Nital 1.5%.

Prior to etching the sides were wet-finely ground on SiC-paper of different grades in the order indicated in Table 2-7. Etching was performed immediately after polishing with the 1200 type SiC-paper. After etching, the samples were cleaned with ethanol, dried with compressed air and protected with oil.

Table 2-7 Schematic of the sample preparation process for macro etching

<table>
<thead>
<tr>
<th>Step</th>
<th>Abrasive Paper Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>120</td>
</tr>
<tr>
<td>2</td>
<td>320</td>
</tr>
<tr>
<td>3</td>
<td>500</td>
</tr>
<tr>
<td>4</td>
<td>800</td>
</tr>
<tr>
<td>5</td>
<td>1200</td>
</tr>
</tbody>
</table>

A Konica Minolta Dimage G530 digital camera was used to take photos of the samples.

2.5.8. Microstructure

The micro etching reveals the microstructure of the welded layers and the base material. The side where the hardness indentations had been made was polished a short time on a rotating disk with a 3 μm diamond suspension and lubricant. It was then etched with Marble’s Reagent, Kalling no. 1 or with Nital 1.5%. The latter was used for etching the microstructure of the base material and the former for the weld overlay. The etching operation was carried out by swabbing the sample with a piece of cotton wool wetted in the etching liquid. For the identification of delta ferrite, please refer to microstructure [39].

The etched samples were observed in a Leitz optical microscope equipped with a Kappa DX20L-FW camera.

2.5.8.1. Quantification of Delta Ferrite

In order to determine the volume fraction of delta ferrite present in the welded layers, the ASTM standard designated E562 – 02 was used. The method consists of superposing a grid with a regular array of test points over an image produced by a light microscope. The number of test points falling within an area of delta ferrite are counted and divided by the total number of test points, yielding a point fraction expressed as a percentage. In this case a 9x12 grid was used.
The photos were taken at a depth of 0.43 mm below the surface, to avoid any corrosion attacks that would have made the analysis impossible. For etching the sample, Villella’s Reagent diluted with ethanol was used. The ethanol was added in order to reduce the reactivity of Villella’s Reagent.

**Theoretical Calculation of Delta-Ferrite Content**

The delta ferrite content at the surface was estimated using Schaeffler’s formula [40] for the Schaeffler-DeLong diagram:

\[
C_{\text{req}} = \%\text{Cr} + \%\text{Mo} + 1.5\%\text{Si} + 0.5\%\text{Nb} \quad \text{Equation 2-7}
\]

\[
N_{\text{eq}} = \%\text{Ni} + 30\%\text{C} + 0.5\%\text{Mn} + 30\%\text{N} \quad \text{Equation 2-8}
\]

The \( C_{\text{req}} \) and \( N_{\text{eq}} \) were calculated in three different ways:

1. Using the data given in the specification for the weld material used for the surface layer (cf. Table 2-8).
2. Using the data from the specifications as described above, except for the chromium and nickel content. The chromium and nickel content used were the ones measured with ICP-OES analysis at the surface (cf. Table 2-8).
3. Using SKF’s semi-empirical model for calculating chemical composition which takes into consideration the mixing in the weld pool of the electrode metal with the underlying material.

<table>
<thead>
<tr>
<th>Table 2-8 Chemical composition of the weld overlay materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data source</td>
</tr>
<tr>
<td>--------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
2.6. Results

2.6.1. Size Measurement and Visual Inspection

The diameter and length of the rolls are given in Table 2-9. The diameter measurements of roll no. 1 were all in the interval [151.0; 152.8] mm. That is a span of 1.8 mm. For roll no. 2 the interval was [150.0; 152.6] mm, a span of 2.6 mm.

Table 2-9 Length and average diameter of the rolls.

<table>
<thead>
<tr>
<th>Roll no.</th>
<th>Diameter [mm]</th>
<th>Length [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position A</td>
<td>Position M</td>
</tr>
<tr>
<td>1</td>
<td>152.5</td>
<td>151.8</td>
</tr>
<tr>
<td>2</td>
<td>151.1</td>
<td>151.2</td>
</tr>
</tbody>
</table>

The inner diameter of the rolls is not a constant. Near the ends it is larger, to leave room for the bearings. Regarding both rolls, the total material thickness is 25 mm near the ends and 34 mm everywhere else.

Upon a first visual inspection, the rolls did not seem much worn (cf. Figure 2-30 and Figure 2-31). On both rolls the weld overlaps were clearly visible as dark lines. The approximate widths of the overlaps and weld beads are given in Table 2-10.

Figure 2-30 Photo of roll no. 1, before polishing.

Figure 2-31 Photo of roll no. 2, before polishing.
Table 2-10 Width of weld bead and weld overlap zone.

<table>
<thead>
<tr>
<th>Roll no.</th>
<th>Approximate width of weld overlap [mm]</th>
<th>Approximate width of weld bead (without overlap) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As mentioned above, the weld overlaps appeared like dark lines. After polishing it showed that this was due to pitting corrosion (cf. Figure 2-32). In fact, the corrosion pits were clearly visible on both rolls with a clear concentration in the overlap zones (cf. Figure 2-32).

Figure 2-32 Photos of weld overlaps (finely ground rolls), the distance between each line on the ruler is 1 mm. a) Roll no. 1 position MI. b) Roll no. 2 position MI

The short ends of the rolls were more heavily corroded than the roll mantle (cf. Figure 2-33 a and b). There were also some traces of a white substance, probably mould flux. The peripheries of the short ends of roll no. 1 were less heavily corroded (cf. Figure 2-33a).

Figure 2-33 a) Roll no. 1 short end B. b) Roll no. 2 short end B.
2.6.2. Ultrasonic Testing

No cracks were detected in the rolls. However, several pores and slag inclusions were detected. The diameter of the pores probably did not exceed 0.5 mm. These pores and slag inclusions were not concentrated to any particular area of the roll.

2.6.3. Hardness Testing

2.6.3.1. Surface Hardness

No significant difference in surface hardness was observed between the two rolls. In Table 2-11 the average value of surface hardness is presented.

Table 2-11 Average surface hardness in the weld bead.

<table>
<thead>
<tr>
<th>Roll no.</th>
<th>HV1</th>
<th>95 % CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>445.5</td>
<td>5.3</td>
</tr>
<tr>
<td>2</td>
<td>452.8</td>
<td>12.9</td>
</tr>
</tbody>
</table>

The hardness measured in the weld overlap is slightly higher than that measured in the bead. This difference is particularly noticed in the case of roll 2. All results are shown in Figure 2-34.

Figure 2-34 Average surface hardness of roll 1 and 2 measured in different positions. The error bars represent the 95% confidence interval. For values in HRC, please refer to Appendix I Figure 1.
2.6.3.2. Hardness Profile

The hardness profile of roll 1 has three plateaus while roll 2 has only two. In Figure 2-35 and Figure 2-36 the hardness profiles of both rolls are presented.

Figure 2-35 Hardness profile of roll 1 in the Y direction measured in different positions. For values in HRC, please refer to Appendix I Figure 2.

Figure 2-36 Hardness profile of roll 2 in the Y direction measured in different positions. For values in HRC, please refer to Appendix I Figure 3.
2.6.4. Chemical Composition

2.6.4.1. Nickel and Chromium Profile by ICP-OES Analysis

The precision of the ICP-OES analysis is ± 2.5%. Ni content in the surface of roll 1 is between 2.0 – 2.5 wt% and gradually drops off to attain a stable value of approximately 0.1 wt% at a depth equal to 9 mm, cf. Figure 2-37. The content of Ni at the surface of roll 2 is around 3.0 wt% and drops off gradually to attain a stable value of 0.2 wt% at a depth of 6 mm, cf. Figure 2-38.

![Nickel Content vs Depth](image)

Figure 2-37 Nickel content in roll 1 at different positions (always in the bead), as a function of the depth below the roll surface. The ‘Model’ curve comes from the SKF model.
Figure 2-38 Nickel content in roll 2 at different positions (always in the bead), as a function of the depth below the roll surface. The ‘Model’ curve comes from the SKF model.

Figure 2-39 Nickel content in the roll surface at different positions.

Cr content in the surface of roll 1 is between 11 wt% and gradually decreases to attain a stable value of approximately 0.1 wt% at a depth equal to 9 mm, cf. Figure 2-40. The content of Cr at
the surface of roll 2 is around 12 wt% and gradually decreases to attain a stable value of 1 wt% at a depth of 6 mm, cf. Figure 2-41.

**Figure 2-40** Chromium content in roll 1 at different positions (always in the bead), as a function of the depth below the roll surface. The ‘Model’ curve comes from the SKF model.

**Figure 2-41** Chromium content in roll 2 at different positions (always in the bead), as a function of the depth below the roll surface. The ‘Model’ curve comes from the SKF model.
2.6.4.2. Chemical Composition by Calculations with Semi-empirical Model

The chromium and nickel content as a function of the depth below the surface in roll no. 1 and 2 are given in Figure 2-37, Figure 2-38, Figure 2-40 and Figure 2-41.
2.6.4.3. Surface Carbon Content Analysis by Wet Chemical Method

The carbon content in the surface of roll 1 and 2 is presented in Figure 2-43. The precision of the measurements is approximately ± 0.11%.

![Surface carbon content at different positions on the rolls.](image)

**Figure 2-43** Surface carbon content at different positions on the rolls.

2.6.5. Macrostructure

The Nital 1.5% etching clearly reveals that there are three welded layers on roll 1 and two on roll no. 2 (cf. Figure 2-44). For more photos cf. Appendix II.

![Nital 1.5% macroetching. a) Roll no. 1, position AI, YZ-plane. 3 weld overlays and one base layer. b) Roll no. 2, position MI, YZ-plane. 2 weld overlays and one base layer.](image)
2.6.6. Microstructure

2.6.6.1. Thickness of the Weld Layers

The different weld layers visible after macroetching were also visible in optical microscope after etching with Marble’s Reagent. The thickness of the layers is given in Table 2-12 and Figure 2-35. The relatively thin base material in on Roll no. 1 position AII Bead and Overlap and on Roll no. 2 position AII Overlap is due to the variation in inner diameter as described in paragraph 2.6.1.

Table 2-12 Approximate thickness of the different weld layers and the base material on roll no.1.

<table>
<thead>
<tr>
<th>Thickness [mm]</th>
<th>Roll no. 1</th>
<th>Roll no. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AII</td>
<td>MI</td>
</tr>
<tr>
<td>Bead</td>
<td>Overlap</td>
<td>Bead</td>
</tr>
<tr>
<td>Thickness [mm]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bead</td>
<td>Overlap</td>
<td>Bead</td>
</tr>
<tr>
<td>Thickness [mm]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bead</td>
<td>Overlap</td>
<td>Bead</td>
</tr>
<tr>
<td>Thickness [mm]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2-13 Approximate thickness of the different weld layers and the base material on roll no. 2.

<table>
<thead>
<tr>
<th>Thickness [mm]</th>
<th>Roll no. 2</th>
<th>Roll no. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AII</td>
<td>MI</td>
</tr>
<tr>
<td>Bead</td>
<td>Overlap</td>
<td>Bead</td>
</tr>
<tr>
<td>Thickness [mm]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bead</td>
<td>Overlap</td>
<td>Bead</td>
</tr>
<tr>
<td>Thickness [mm]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.6.6.2. Microstructure of the Weld Layers

The microstructure of the weld layers of the rolls is mainly martensitic. As can be seen in Figure 2-45 and Figure 2-46, the microstructure is inhomogeneous it varies between the different layers as well as within each layer (cf. Figure 2-47). The microstructure in the weld overlaps is similar to that in the beads. However, the overlaps have suffered more corrosion attacks than the beads (cf. Figure 2-50). For more photos of the microstructure cf. Appendix III.
**Figure 2-45** Position AII bead. Etched with Marble's Reagent.  
**a)** Roll no. 1 Microstructure at the surface (layer 3).  
**b)** Roll no. 2. Microstructure at the surface (layer 2).

**Figure 2-46** Position AII bead. Etched with Marble's Reagent.  
**a)** Roll no. 1 Detail of the microstructure at the surface (layer 3).  
**b)** Roll no. 2. Detail of the microstructure at the surface (layer 2).

**Figure 2-47** Roll no. 1, Position AII bead. Transition weld layer 2 - 1. Etched with Marble’s Reagent. Layer 1 was more heavily attacked by the reagent than layer 2.
2.6.6.3. Delta Ferrite in the Weld Layers

In both rolls, the microstructures of the weld layers contained various quantities of delta ferrite (cf. Figure 2-48 a). The delta ferrite was present either as a continuous network (cf. Figure 2-48 b) or as isolated grains in the mainly martensitic matrix (cf. Figure 2-49 a). The delta ferrite network seemed to be a preferential site for corrosion attacks from the surface (cf. Figure 2-49 b). Delta ferrite was detected in all weld layers of both rolls and was evenly distributed in each roll.

![Figure 2-48 a) Roll no. 2, position MII bead. Etched with Kalling. Microstructure at the surface (layer 2). Delta ferrite (dark) in a martensitic matrix. The microstructure is columnar, as described in the previous paragraph. b) Roll no. 1 position MII overlap, layer 3. Etched with Marble's Reagent. Delta ferrite network in martensite.](image)

![Figure 2-49 Roll no. 1, position MII overlap, layer 3. Etched with Marble's Reagent a) Isolated delta ferrite in martensite. b) Corrosion attacking delta ferrite network.](image)

2.6.6.4. Corrosion Attacks on the Weld Layers

The attacks followed the delta ferrite network (cf. Figure 2-50). The extent and form of the corrosion attacks varied, some positions were not attacked at all, some only a little (cf. Figure 2-51a) and some more heavily (cf. Figure 2-51b). The results of our observations are summarized in Table 2-14 and Table 2-15. The more severe corrosion attacks lead to cracking. The cracks could be parallel or perpendicular to the roll surface. The cracks parallel to the surface are generally longer than the ones perpendicular to the surface. Cracks only appeared in zones suffering corrosion.
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Figure 2-50 Etched with Marble’s Reagent. Surface. a) Roll no. 1. Position MII overlap. Martensitic structure with delta ferrite network (dark lines) and isolated corrosion pitting and cracking. b) Roll no. 2. Position MI overlap. Martensitic structure with delta ferrite network (dark lines) and corrosion attack in form of a interconnected network with cracking.

Figure 2-51 a) Roll no. 1, position MI overlap, unetched. Surface with corrosion attacks in form isolated network with cracking and pits. b) Roll no. 2, position MI overlap, unetched. Corrosion attack in form of an interconnected network with pits and cracking cover the whole surface.

Table 2-14 Extent of the corrosion attacks on roll no. 1.

<table>
<thead>
<tr>
<th>Extent of the attacks$^1$</th>
<th>Roll no. 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Bead Overlap</td>
<td>Bead Overlap</td>
</tr>
<tr>
<td>No attacks</td>
<td>A few isolated attacks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Corrosion network$^2$</th>
<th>Roll no. 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Deepest attack [mm]</th>
<th>Roll no. 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

1. An estimation of the extent of the corrosion attacks on the surface: Whether the whole surface is attacked (cf. Figure 2-51b), or if there are just a few isolated attacks (cf. Figure 2-51a), or no attacks at all.
2. Whether the corrosion attacks are in form of a network (cf. Figure 2-51 and) or isolated (cf. Figure 2-51).
### Table 2-15 Extent of the corrosion attacks on roll no. 2.

<table>
<thead>
<tr>
<th>Extent of the attacks</th>
<th>Roll no. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AII</td>
</tr>
<tr>
<td>Bead</td>
<td></td>
</tr>
<tr>
<td>Overlap</td>
<td></td>
</tr>
<tr>
<td>A few isolated attacks</td>
<td>No</td>
</tr>
<tr>
<td>The whole surface attacked</td>
<td>No</td>
</tr>
<tr>
<td>Deepest attack [mm]</td>
<td>0.19</td>
</tr>
</tbody>
</table>

### 2.6.6.5. Microstructure of the Base Material

![Microstructure](image1.png)

*Figure 2-52* In the middle of the base material. Etched with Nital 1.5%. *a)* Roll no. 1 Ferritic-perlitic structure *b)* Roll no. 2. Tough hardened tempered martensitic structure

### 2.6.6.6. Delta Ferrite Quantification

The delta ferrite content in roll number 1 is 3.07 vol. % in the weld bead and 2.90 vol. % in the weld overlap. The confidence interval is 0.55 and 0.42 respectively. Regarding roll number 2, the delta ferrite content is 6.60 vol. % in the weld bead and 7.28 vol. % in the overlap. The confidence interval is 0.59 and 0.68 respectively. The results are shown in Figure 2-53.
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**Figure 2-53** Average delta ferrite content of roll 1 and 2 measured in different positions. The error bars represent the 95% confidence interval. The values above the error bars represent the average.

**Delta Ferrite Content by Theoretical Calculations**

The results of the theoretical calculations are given in Table 2-16 and illustrated in Figure 2-54 and Figure 2-55. The value of the delta ferrite content is estimated from the Schaeffler-DeLong diagram.

**Table 2-16** $C_{eq}$, $N_{eq}$ and delta ferrite content from theoretical calculations.

<table>
<thead>
<tr>
<th>Data source</th>
<th>Roll no.</th>
<th>$C_{eq}$</th>
<th>$N_{eq}$</th>
<th>Delta ferrite %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Welding Specification</td>
<td>1</td>
<td>15.0</td>
<td>8.0</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>16.2</td>
<td>6.7</td>
<td>17</td>
</tr>
<tr>
<td>2. Welding Specification + ICP-OES analysis</td>
<td>1</td>
<td>13.4</td>
<td>7.3</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>15.6</td>
<td>7.2</td>
<td>10</td>
</tr>
<tr>
<td>3. SKF semi-empirical model.</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure 2-54 Schaeffler-Delong Diagram for Roll no. 1. The grey dot represents the calculations using data from the specification. The black dot represents the calculations using the specification but with Cr% and Ni% from ICP-OES analysis. The white dot represents the calculations with SKF’s semi-empirical model.

Figure 2-55 Schaeffler-Delong Diagram for Roll no. 2. The grey dot represents the calculations using data from the specification. The black dot represents the calculations using the specification but with Cr% and Ni% from ICP-OES analysis. The white dot represents the calculations with SKF’s semi-empirical model.
2.7. Discussion

2.7.1. Roll Diameter
The diameter measurements of roll no. 1 and 2 show some difference between the positions A, M and B. However none of the measures is below 150.0 mm, which is the diameter given in the specification. This indicates that the rolls have not suffered any significant wear.

The calliper might not have been perfectly perpendicular to the rolls when the measurements were carried out. This is a possible source of error.

2.7.2. Chemical Composition

2.7.2.1. ICP-OES Analysis
There was no big difference between the chromium and nickel content at the different positions in roll no. 1. The same is true for roll no. 2.

Roll no. 1
The chromium and nickel content at the surface (cf. Figure 2-39 and Figure 2-42). This is probably due to some chromium and nickel escaping with the welding fumes, as well as mixing of the electrode with underlying material.

The high chromium content of layer 1 causes an immediate rise of the chromium level at the depth of 7 mm (cf. Figure 2-56). At the depth of 4 mm the nickel contents increases strongly.

Roll no. 2
The chromium content at the surface is lower than the value in the weld material (cf. Figure 2-42). As in the case of roll no. 1, this is probably due to mixing with underlying material and evaporation with the welding fumes. The nickel content at the surface is actually higher than what is specified for the weld material (cf. Figure 2-39). This means that during the welding more nickel was added, probably from the electrode, than what is specified (The weld flux OK Flux 10.61 does not contain any alloying elements).

The chromium and nickel curves have same profile (cf. Figure 2-56). This is normal, since only one type of weld material was used.

In reality, the chromium content is approximately 1.1 wt% and the nickel content is 0.2 wt%.

The base material in roll no. 1 contains no chromium and nickel, and no negative effects have been observed that are due to this fact.
Discrepancy with the specification in the base material of roll no. 2 has no practical effect on the performance of the roll.

**Difference Between Weld Overlap and Bead**

The chromium content at the surface was generally higher in the weld beads than in the weld overlaps (cf. Figure 2-42). The difference is small, 0.5 wt%, but the trend is quite strong (7 samples out of 8). The nickel content at the surface follows the same trend: in 7 samples out of 8, the nickel content is higher in the bead than in the overlap (cf. Figure 2-39).

During the welding some nickel and chromium will escapes with the welding fumes from the pool of liquid metal. The repeated heating of the overlap zones causes more nickel and chromium to escape. This explains why the chromium and nickel content is lower in the overlap zones.

The difference in chromium content between the weld beads and the overlap zones could also be due to sensitisation (chromium carbide precipitation). It is probable that the temperatures at which sensitisation occurs are attained during the repeated heating of the overlap zones during the welding. This means that the chromium content can be very low locally on the grain boundaries, without changing the overall chromium content very much.

---

**Figure 2-56** Comparison of the chromium and nickel content variation with the depth below the surface at position Al.
Sources of Error
The ICP-OES analysis is very precise. However, for the precision of the analysis it is important to collect a sufficient quantity of material for each sample. This quantity was always respected. What is equally important is to collect the samples with sufficient precision and not to mix material from different samples. Care was taken to avoid these errors, as described in paragraph 2.5.6.1.

2.7.2.2. SKF Semi-empirical Model
The nickel and chromium content are overestimated regarding roll no. 1, but underestimated regarding roll no. 2. In all cases, the model predicts that the increase in chromium / nickel content will occur “earlier”, i.e. at a greater depth below the surface, than what is observed with the ICP-OES analysis. Neglecting this, the maximum error is approximately 1 wt% for both the chromium and the nickel calculations. The model gives a rough estimation of the nickel and chromium content profiles, but can not replace an ICP-OES analysis. The model needs some adjustments to give more precise predictions.

2.7.2.3. Surface Carbon Content
The surface carbon content was about 0.12 wt%, for both rolls.

2.7.3. Macrostructure and Microstructure

2.7.3.1. Microstructure
The rolls had the microstructure they were expected to have: tempered martensite with some delta ferrite in the weld overlay and ferritic-perlitic or tough-hardened tempered martensite in the base material.

The microstructure of the weld overlays was very inhomogeneous. Generally it had a columnar solidification structure, which is typical for a welded material. No major differences were observed in the microstructures of the weld overlays of the two rolls. The only exception to this was layer 1 of roll no. 1, which differed significantly from the two outer layers (cf. Figure 2-47 a).

2.7.3.2. Delta Ferrite
The delta ferrite is a preferential site for the corrosion attacks. Delta ferrite is basically pure iron and therefore very sensitive to corrosion. Isolated delta ferrite is not very dangerous, since the surrounding material will not corrode easily. When there is a delta ferrite network, corrosion can spread easily throughout the material. The mechanical properties of the material diminish.

Roll no. 1 contained approximately 3% delta ferrite and roll no. 2 contained 7% at a depth of 0.4 mm below the surface. The delta ferrite was present in all weld layers and seemed

The theoretical calculations of the delta ferrite content based on the chemical composition indicated that there was a difference between the two rolls. The semi-empirical model and the calculations using only data from the welding specification showed serious discrepancy with the results from the empirical quantification (cf. Table 2-17). The theoretical calculation using the
welding specification, but with the chromium and nickel content from the ICP-OES analysis, proved to be closest to the measured values from the delta ferrite quantification.

### Table 2-17 Delta ferrite content according to theoretical calculations and empirical quantification.

<table>
<thead>
<tr>
<th>Data source</th>
<th>Roll no. 1</th>
<th>Roll no. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Welding Specification</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>2. Welding Specification + ICP-OES analysis</td>
<td>2.5</td>
<td>10</td>
</tr>
<tr>
<td>3. SKF semi-empirical model.</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Delta Ferrite Quantification</td>
<td>3</td>
<td>7</td>
</tr>
</tbody>
</table>

Roll no. 2 has wider weld beads than roll no. 1. To make a wider weld bead requires more energy input during the welding. A higher energy means a higher temperature during a longer time. Theoretically, this gives time for the delta ferrite to form. For the same reason, the repeated heating of the overlap zones could be expected to favour delta ferrite formation. However, no difference in delta ferrite content between the weld bead and overlap is observed.

The time / temperature factor does not seem to have such a big influence on the delta ferrite formation. As described above, the difference in chemical composition between the two weld overlays is likely to explain the observed difference in delta ferrite content between the two rolls.

#### 2.7.3.3. Macrostructure and Thickness of the Weld Overlays

When observing the macrostructure of roll no. 1, layer 2 and 3 appeared very similar and the transition between them was barely discernible. However, layer 1 differed significantly from the two outer layers. Variations in chemical composition and solidification conditions explain this difference.

The different weld layers of the rolls were clearly visible, both on the macroscopic and microscopic scale. One should keep in mind that the numbers given in Table 2-12 and Table 2-13 are only rough approximations; in reality the thickness of the layers varies with several millimetres as shown in Figure 2-44.

As mentioned previously, roll no. 1 has a thicker weld overlay than roll no. 2, due to three welded layers instead of two. This makes it possible to skim cut roll no. 1 several times as it gets worn and put back into the continuous casting machine without re-welding. Roll no. 2 will have to be re-welded more frequently.

#### 2.7.4. Hardness

Both rolls had similar surface hardness and therefore one can not say that in this aspect one roll has a better performance than the other. On roll no. 2, the overlap zone was significantly harder than the beads. The same trend is observed on roll no. 1, but not so strongly. The higher hardness in the overlaps could be due to the presence of hard chromium carbides from sensitisation. For roll no. 2, another possible explanation is that closely spaced corrosion pits with oxides cause the high hardness values. The pits were so closely spaced that no measurements could be made between them, but had to be made on them. On roll no. 1 the corrosion pits were not so closely spaced and the measurements were made in the area between them.
There is no big difference between the weld bead and the weld overlap for the hardness profile of roll no. 1. Nor is there any significant difference between the centre of the roll (M) and the end (A). The same is true for roll no. 2. The hardness of the AII bead position of both rolls fits well with the different weld layers (cf. Figure 2-57).

The two outer layers of both rolls have approximately the same hardness. This is explained by the fact they have a similar chemical composition and similar microstructure.

On roll no. 1 the nickel content drops at the same time as the hardness, On roll no. 2 the nickel and chromium contents drop well before the transition between layer 1 and the base material.

The hardness depends more on the microstructure than on the chemical composition. The microstructure is not entirely dependent on the chromium and nickel content. The solidification conditions – time and temperature – have a big influence on the microstructure.

There is a mixing phenomenon in the transition between the layers. When an additional layer is welded on the roll, the underlying metal will melt. This is why the drops of the chromium and nickel content are not found immediately on the metallographic border between the weld layers.

Figure 2-57 Hardness profiles of the position AII weld beads of roll no. 1 and 2. The positions of the different weld layers, as observed in microscope, are indicated for each sample. The banners marked with Cr or Ni indicates where the Chromium or Nickel levels start to drop significantly.
2.7.5. Corrosion Attacks

2.7.5.1. Comparison Between the Rolls

The corrosion attacks followed the delta ferrite network. Delta ferrite is basically pure iron and therefore very sensitive to corrosion. The microscopy showed that the weld beads of roll no. 1 were undamaged, while as those of roll no. 2 had some isolated corrosion pits. The overlap zones of roll no. 2 had a continuous network of corrosion attacks with cracks and pits in the surface. The overlap zones of roll no. 1 observed in microscope had the same morphology, but the whole surface was not attacked. In fact, no sign of the big corrosion pits observed on roll no. 1 during the visual inspection, was detected by microscopy. This could be due to the fact that none of these pits was present in the samples that were studied.

On both rolls, the deepest corrosion attacks observed in microscope were about 0.6 mm. More attacks of this size were observed on roll no. 2 than on roll no. 1. This makes it more probable to have serious problem with roll no. 2.

Since roll no. 1 has only half as much delta ferrite (about 3%) as roll no. 2 (7%), it is not surprising that the surface of the latter is more corroded. These results can be compared with the ones described by [40], who obtained intergranular delta ferrite when the delta ferrite content exceeded 2% and isolated delta ferrite islands when the content was below 2%.

Sensitisation may also have some influence on the difference in corrosion attacks between the two rolls. This can not be proved but will be discussed in the following paragraphs.

2.7.5.2. Comparison Between Weld Bead and Overlap

The visual inspection of the rolls showed that the weld overlap zones were the most attacked by corrosion. The attacks on the overlaps of roll no. 1 consisted of big pits with a surface of several square millimetres. Between these big pits were relatively big undamaged surfaces (cf. Figure 2-32 a). The attacks on the overlaps of roll no. 2 consisted of very small and closely spaced corrosion pits (cf. Figure 2-32 b).

Since the delta ferrite content was the same in the beads and in the overlaps on both rolls, there must be another explanation to why the overlaps are more attacked by corrosion. The nickel and chromium content is lower in the overlap than in the bead. However the difference is not very big, even though the trend is quite strong (7 samples out of 8). As discussed in paragraph 2.7.2.1,
this can be due to either evaporation with the welding fumes and/or sensitisation (in the case of chromium).

The evaporation occurs before the metal solidifies. This leads to a slightly lower overall chromium and nickel content. This does not explain the difference in corrosion attacks between the beads and the overlaps.

Sensitisation occurs after that the metal has solidified and leads to a lowered chromium content locally near the grain boundaries. This could explain the difference in corrosion attacks between the beads and the overlaps. To confirm this, further analysis would be necessary.

2.7.6. Methods

In the beginning of the study the assumption was made that if the visual inspection, surface wear (diameter measurement), ultrasonic testing and surface hardness showed that all positions on the roll were similar, the hardness, microstructure and chemical composition would also be similar at all positions. This assumption proved to be true. In any future study, it should be sufficient to cut a bead and overlap sample from one position, on condition that the visual inspection, diameter measurements and surface hardness measurements show that all positions on the roll are similar.

Marble’s Reagent is appropriate for studying the microstructure of the weld overlay. Nital 1.5% is appropriate for studying the microstructure of the base material and for studying the macrostructure of both weld overlay and base material. Villella’s Reagent and Kalling no. 1 are both appropriate for revealing delta ferrite in the weld overlay.

The delta-ferrite quantification was easily done following the ASTM-standard.

The ICP-OES analysis was efficient and reliable for determining the chemical composition. It was very efficient to use a small magnet strip to collect the borings when drilling.
2.8. Conclusions and Recommendations

The weld overlaps are clearly the weakest points of the weld overlay as they are sensitive to corrosion attacks. This is probably due to sensitisation.

The delta ferrite is a preferential site for the corrosion attacks and the delta ferrite content depends primarily on the chemical composition of the weld overlay. The welding temperature may also have some influence on the delta ferrite content, but this has not been observed in this study.

Both rolls have similar surface hardness. Roll no. 2 has more generalized corrosion attacks than roll no. 1. This is due to a higher delta ferrite content in roll no. 2 than in roll no. 1.

If sensitisation becomes a greater problem, a martensitic stainless steel with lower carbon content and strong carbide formers other than chromium could be used.

For further studies it would be of interest to study the effects of a solution treatment after welding, to evaluate the performance of open arc welded overlays and to compare the performance of welded rolls with centrifugally cast martensitic stainless steel rolls. The influence of grooves on roll-life is another highly interesting topic.

In any future study, on condition that the visual inspection, diameter measurements, hardness testing and surface hardness measurements show that all positions on the roll are similar, it will be sufficient to cut a bead and overlap sample from only one position.
3. Industrial Buying Behaviour Study

3.1. Abstract

The aim of this study is to investigate the industrial buying behaviour in slab casting steelworks in Western Europe when buying roll-lines. Case studies have been conducted at four steelworks belonging to different companies. Data was collected through personal interviews with people from production, maintenance and purchasing department and intermediate level management.

A test consisting of a smaller amount of rolls is always performed before buying any larger quantities of rolls. Even though the test order has relatively low economic value, compared to a full scale order, it is during this process that the relationships are established between the buying and the selling company. Findings show that the industrial buying behaviour of steelworks in Western Europe agrees well with the theory in this field. The buying process follows the steps in the buygrid model with only a few exceptions. The decision-making power lays in the intermediate level management, even though approval is required from upper level management. The most important factors affecting the buying behaviour are the relationship between the buyer and the seller, service-life and life-cycle cost of the roll-line.
3.2. Introduction and Research Problem

3.2.1. Introduction

The fundamental purpose of a company is to generate profit, and for that it needs to sell. In a world of ever stiffening competition the task of selling is growing increasingly complex; "to survive in selling today, you need strategy" [41].

Industrial marketing strategies are built on knowledge about the buyers. Hence, understanding the behaviour of organizations when they are buying is of vital importance when working with industrial marketing. Organizational buying behaviour or industrial buying behaviour1 has been defined as a "complex process of decision making and communication which takes place over time involving several organizational members and relationships with other firms and institutions" [42].

The aim of this study is to understand the buying behaviour in a particular line of industry (continuous slab casting steelworks) in a particular region (Western Europe).

In this chapter the background of the study will be discussed leading to the research problem formulation. The disposition of the study will be provided at the end of the chapter.

3.2.2. Background

3.2.2.1. Industrial Buying Behaviour

In the field of marketing studies, industrial buying behaviour studies focus on how companies buy goods and services. Understanding the industrial buying behaviour is "the cornerstone of industrial marketing strategy" [43].

3.2.2.2. Augmented Products - Selling a Solution

"The new competition is not between what companies produce in their factories, but between what they add to their factory output in form of packaging, services, advertising, customer advice, financing, delivery arrangements, warehousing, and other things that people value" [44].

Products can be divided into three separate levels: core benefit, actual product and augmented product (cf. Figure 3-1). What the customer really buys is called the core benefit. What is included in the actual product is the core benefit plus the product features, quality level, brand name, packaging and design. The augmented product includes the actual product and additional customer services and benefits, such as delivery and credit, installation, warranty and after-sale service [45]. Selling an actual product can be equivalent to selling a component, whereas selling an augmented product is equivalent to selling a solution.

Many companies prefer buying a "packet solution" from one supplier, thus avoiding the complex multiple decisions process of buying components. The supplier who can offer the most complete

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1 In this report, the terms organizational buying behaviour and industrial buying behaviour will be used as synonyms and sometimes referred to as IBB.
system, i.e. solution, to meet the customer's need, often wins the contract. *Systems selling* is a key business marketing strategy in order to be successive [Ibid].

![Diagram of the three different levels of a product](image)

**Figure 3-1** A representation of the three different levels of a product [45].

### 3.2.2.3. Industry and Scope of the Study

Steel is one of the most well-known and commonly used materials in the world. During the last decade there has been a boom of the steel producing capacity, mainly due to the large expansion of the Chinese steel industry. At the same time, the world consumption has risen dramatically, due to the growth of the Chinese economy.

Western Europe has a long tradition of steel making. The oil crisis in the early seventies forced a great number of steelworks to close down. The remaining work increased their productivity greatly, due to technical improvements. Today Chinese competitors challenge the steelworks in Western Europe. This dynamic market situation, in combination with the relatively small cultural differences, makes Western Europe an interesting region to study.

The continuous casting method is used for over 90% of the world steel production today [3]. Roll-lines are vital parts in the production facilities of the continuous casting steelworks. Due to harsh service conditions, these capital goods have to be replaced and / or reworked with a relatively high frequency, up to several times per year. They are considered a limiting factor for the production capacity. Moreover, the use of lubricants necessary for the roll-lines is an environmental problem.

In some cases steelworks with continuous casting machines outsource the production and / or the rework of steel casting roll-lines. In other cases they do the maintenance, and buy the components and assemble the roll-lines themselves. In some cases they even produce many of the components themselves.

SKF is the world's leading bearing supplier. The company has quite recently decided to go from selling *components* to become a knowledge-based company selling *solutions*. In line with this new strategy, SKF is since 2001 offering a complete roll-line solution, called ConRo, including service and maintenance. As a new actor on the market, striving to sell a solution to customers used to
buy components; the company is now trying to better understand the market demand in order to secure continued sales of a complete ConRo system.

3.2.3. Research Problem

In the previous sections the background of this study was presented. We discussed the importance of understanding IBB in marketing activities as well as the notion of augmented products. The significance of the steel industry and the importance of continuous casting rolls were underlined. The relevance of studying the steel industry in Western Europe was indicated.

At the present, we have chosen the scope of the study. Based on what has been outlined in the previous sections, we are now able to formulate our research problem:

**How can the industrial buying behaviour of steel companies in Western Europe be characterized when buying roll-lines?**

3.2.4. Outline of the Study

The study is divided into six parts containing seven chapters: Introduction and Research Problem, Overview of Literature, Frame of Reference, Methodology, Case Studies, and is also performing repair and rework and. The outline of the study is illustrated in Figure 3-2.

![Figure 3-2 Outline of the study.](image)

3.2.5. Roll-lines

A roll-line consists of several continuous casting rolls mounted together as shown in Figure 3-3. The roll-lines are a part of the continuous casting machine. Usually there are between 350 and 750
rolls in a continuous casting machine. The functioning of this machine will be described in the following paragraph.

![Figure 3-3](image) A roll-line with three rolls.

In the continuous casting process molten steel is transformed into long semi finished products of constant cross section on a continuous basis (Figure 3-4). This process is used to manufacture about 90% of all the steel currently produced worldwide [46].

![Figure 3-4](image) Schematic presentation of the continuous casting process [47].

In the continuous casting machine (CCM), molten metal is tapped into the ladle from furnaces. From the ladle, the hot metal is transferred to a holding bath called a tundish.

A thin layer of metal next to the mould walls solidifies before the metal section, now called a strand, exits the base of the mould into the cooling-chamber. In the cooling-chamber the strand is supported by rolls and large quantities of water is sprayed on the strand in order to increase the rate of solidification and to cool the rolls. At this stage, the risk of breakout occurring is greatest. A breakout is when the solidified strand surface breaks and liquid steel leaks out.

After exiting the cooling-chamber, the strand passes throughstraightening rolls and withdrawal rolls and is cut into determined lengths in the cutter.
The rolls investigated in this study are located in the continuous casting machine just beneath the mould, in the cooling chamber (cf. Figure 2-1).

For a more detailed technical background, please refer to chapter 2.4 in the Metallurgical Study.
3.3. Overview of Literature

3.3.1. Introduction

The literature has been chosen to reflect the research problem presented in section 3.2.3. The relevant terminology concerning IBB will be discussed. Special attention will be paid to the buying process, the buying centre and factors affecting the buying process and the buying centre.

A more thorough overview of literature has been done by Baptista and Forsberg [48]. They have studied the buying behaviour of Swedish and Polish Mining Industry when purchasing capital equipment. Both studies, their and ours, concern the buying behaviour in heavy industry when purchasing machinery (i.e. capital goods1), used in the production of intermediate goods2. Therefore we have chosen to use the same models to investigate the industrial buying behaviour.

3.3.2. Industrial Buying Behaviour

According to [49], there is a difference between transactional and relational buying behaviour. Relational and cooperative buying behaviour is called the modern buying philosophy, while as transactional and competitive buying behaviour is called the classical buying philosophy.

<table>
<thead>
<tr>
<th>The Classical Buying Philosophy</th>
<th>The Modern Buying Philosophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Transactional and competitive directed)</td>
<td>(Relational and Cooperative Directed)</td>
</tr>
<tr>
<td>- Many alternative suppliers (3 or more).</td>
<td>- One or few (or two alternative) suppliers.</td>
</tr>
<tr>
<td>- Exploit the potential of competition.</td>
<td>- Exploit the potential of cooperation.</td>
</tr>
<tr>
<td>- Short perspective - every purchase is seen as a new decision.</td>
<td>- Long-term perspective - problems will be solved within the relationship.</td>
</tr>
</tbody>
</table>

The philosophy is often congruent with a way of working in the company characterized by:

| Local problem solving, purchasing department solves problems related to buying.  | Cooperative problems solving, buying department cooperates.  |

The philosophy is clearly focused on something that can be summarized by the words:

| PRICE ORIENTATION  | COST ORIENTATION |

Figure 3-5 The modern and the classical buying philosophy [49].

These two buying philosophies are quite different from one another. The latter is by many companies seen as the way that the company should work with their purchases. However, the former still seem to be dominant [ibid]. Depending Of course, this very much depends on the type and the size of the company, as well as the type and the size of the purchase.

---

1 Capital goods are tangible items such as buildings, machinery, and equipment produced and used in the production of other goods and services.

2 Intermediate goods are goods manufactured and used in further manufacturing, processing, or resale.
According to [50], studies of IBB will fall into one of three different "areas": buying process, buying centre and factors affecting the buying process and the buying centre. These areas will be discussed in the following paragraphs.

3.3.2.1. Buying Process

Industrial buying is more of a process than of an event. The *Buygrid Framework* model was developed by [51]. It is a conceptual framework for the analysis of industrial buying situations. The purchase is divided into eight *buyphases*:

1. Anticipation or recognition of a problem and a general solution
2. Determination of characteristics and quantity of a needed item
3. Description of characteristics and quantity of a needed item
4. Search for and qualification of potential sources
5. Acquisition and analysis of proposals
6. Evaluation of proposals and selection of supplier(s)
7. Selection of an order routine
8. Performance of feedback and evaluation

Three different types of *buying situations* were also described [Ibid]. The type of situation depended on the newness of the problem, the information requirements and the consideration of new alternatives. The different types of buying situation are illustrated in Table 3-1.

<table>
<thead>
<tr>
<th>Type of Buying Situation</th>
<th>Newness of Problem</th>
<th>Information Requirements</th>
<th>Consideration of New Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Task</td>
<td>High</td>
<td>Maximum</td>
<td>Important</td>
</tr>
<tr>
<td>Modified Rebuy</td>
<td>Medium</td>
<td>Moderate</td>
<td>Limited</td>
</tr>
<tr>
<td>Straight Rebuy</td>
<td>Low</td>
<td>Minimal</td>
<td>None</td>
</tr>
</tbody>
</table>

The buyphases and the buying situations are combined into the buygrid framework as shown in Table 3-2.

Referring to the buygrid in Table 3-2, the most complex buying situations will occur in the upper left part, i.e. New Task. Then, all the different buyphases will be important, though the first phases will be crucial. In the case of a modified rebuy the early and the latter phases will be most important to the buying process. In a straight rebuy, the emphasis will be on the latter phases of the process, the earlier will be of little importance.
Table 3-2 The buygrid framework [51].

<table>
<thead>
<tr>
<th>Buyphase</th>
<th>Buyclasses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>New Task</td>
</tr>
<tr>
<td>1. Anticipation or recognition of a problem and a general solution</td>
<td>Yes</td>
</tr>
<tr>
<td>2. Determination of characteristics and quantity of a needed item</td>
<td>Yes</td>
</tr>
<tr>
<td>3. Description of characteristics and quantity of a needed item</td>
<td>Yes</td>
</tr>
<tr>
<td>4. Search for and qualification of potential sources</td>
<td>Yes</td>
</tr>
<tr>
<td>5. Acquisition and analysis of proposals</td>
<td>Yes</td>
</tr>
<tr>
<td>6. Evaluation of proposals and selection of supplier(s)</td>
<td>Yes</td>
</tr>
<tr>
<td>7. Selection of an order routine</td>
<td>Yes</td>
</tr>
<tr>
<td>8. Performance of feedback and evaluation</td>
<td>Yes</td>
</tr>
</tbody>
</table>

3.3.2.2. Buying Centre

According to [51]: "The individuals who are related directly to the purchasing process, whether users, buying influences, decision makers, or actual purchasers are members of what can be termed a 'buying centre'." The buying centre concept was actually introduced by [51]. However, they called it the "decision making unit". The name buying centre was given by [52].

According to [50], there are three different aspects to the buying centre:

- **Composition** of the buying centre
- **Roles** in the buying centre
- **Influence** in the buying centre

**Dimensions of the Buying Centre**

When analysing the composition of the buying centre, the findings will be related to concepts such as *size*, *hierarchical levels* and *functional areas* involved. If an individual have participated in the communication network concerning the purchase under investigation, it is considered to be a part of the buying centre.
To further clarify the analysis of the buying centre, [53] proposes the following dimensions of the buying centre:

- **Extensivity**: The number of people from the buying centre involved in the buying communication.
- **Lateral involvement**: The number of departments involved in the buying centre.
- **Vertical involvement**: The number of authority levels that influence the communication within the buying centre.
- **Connectedness**: The degree to which the buying centre members are linked to each other by direct communications.
- **Centrality**: The degree to which the purchasing manager acts as a centre of communication within the buying centre.

The lateral involvement was discussed by [54]. He claims that, in a typical industrial setting, members of at least three different departments are continuously involved in different phases of the buying process. Most commonly, it is personnel from the purchasing, quality control and manufacturing departments.

Different variables will influence the composition of the buying centre. These variables can be divided into two groups [55]:

- **Variables related to the organizational structure**
- **Variables related to the purchase situation**

Johnston and Bonoma [53] describe eight variables influencing the composition of the buying centre. Four of these were related to the organizational structure:

- **Size**: Annual sales in dollars.
- **Complexity**: Number of divisions / subsidiaries.
- **Formalization**: Percentage of the buying process that is written.
- **Centralization**: Organization and operation of the purchasing function of the firm: centralized, decentralized or a combination.

The other four were related to the purchase situation:

- **Importance**: Average of entire buying centre's perceived importance.
- **Complexity**: Time required to complete the buying process.
- **Novelty**: Buy-grid categorization: new task, modified rebuy or straight rebuy.
- **Purchase class**: Type of purchase, e.g. capital equipment or industrial services.

Depending on the buying situation (cf. paragraph 3.3.2.1), the size of the buying centre varies [56]: In straight rebuy situations the buying centre counted two to three members, while as in new task and modified rebuy situations there were three to six persons in the buying centre.
The type of product purchased also influences the buying centre. For instance, [53] observed differences in the dimensions of the buying centre between the purchase of capital equipment and services:

- Extensivity: Significantly more extensive for capital equipment
- Lateral involvement: Generally fewer departments involved in service purchase.
- Vertical involvement: Significantly greater depth (more organizational levels involved) for capital equipment.
- Connectedness: A tendency towards higher connectedness in the purchase of services.

**Roles in the Buying Centre**

According to [42]: "The people involved in organizational buying decisions interact with one another, sharing knowledge and attempting to influence the outcome of the process to their advantage."

In order to better understand and analyse the buying centre, Webster and Wind [52] suggested a model where the members of the buying centre always play five different roles. Each role may be played by one or more of the members. Some members may play several roles at the same time. These roles are:

- **Users**: Those who actually use the purchased products and services.
- **Deciders**: Those who have the authority to choose among alternative buying actions.
- **Influencers**: Those who influence the buying process directly or indirectly by adding information or decision criteria for the evaluation of alternative buying actions.
- **Buyers**: Those with formal responsibility and authority to actually perform the contractual agreements.
- **Gatekeepers**: Those who control the flow of information (and materials) into the buying centre.

A sixth role is added to the buying centre by [57]: the *initiator*. He / She "...recognizes that some company problem can be solved or avoided by acquiring a product or a service", and will initiate the buying process.

According to [54], there are five different areas, which create differential expectations among the individuals involved in the buying process:

- **Background of the Individuals**: The educational background and task orientation of each individual is probably the most influential factor. The former often generates different values and goals in the professional life. The latter may create conflicting perceptions of one another's role in the organization. In addition, the personal life styles of the decision makers play an important role in developing differential expectations.
- **Information Sources and Active Search**: The source and type of information that the different decision makers are exposed to, and their participation in the active search, will also create differential expectations.
- **Perceptual Distortion**: Each individual strives to make the objective information consistent with his own prior knowledge and expectation by systematically distorting it. One should expect different interpretation of the same information from e.g. purchasing agents and engineers.
- **Satisfaction with Past Purchases**: The satisfaction with past buying experiences with a supplier or brand will vary among the individuals. Each individual often have his or her own criteria and priorities, e.g.: quality, price or delivery schedule.
Influence in The Buying Centre

Influence in the buying centre can be seen as "the formal or informal power of a person to affect others or outcomes in buying situations whether or not exerted consciously" [58]. To know who is the most influential person in the buying centre is very important to be able to plan sales efforts. However, measuring the importance of each member in the buying centre can be quite difficult.

According to Bonoma [59], there are five major power bases in an organization.

- **Reward power** refers to a manager's ability to encourage purchases by providing others with monetary, social, political or psychological benefits.
- **Coercive power** refers to a manager's ability to impose punishments on others. Of course threatening punishment is not the same thing as having the actual power to do it.
- **Attraction power** refers to a person's ability to charm or otherwise persuade people to go along with his / her preferences.
- **Expert power** refers to a manager's ability to get others to go along with his judgement because of real or perceived expertise in some area. The person do not have to posses these skills, it is enough that others believe he has them or are willing to respect his opinion because of accomplishments in other fields.
- **Status power** comes from having a high position in the company. It refers to the kind of influence a president has over a first-line supervisor and is more restricted than the other power bases.

3.3.2.3. Factors Affecting the Buying Process and the Buying Centre

Factors affecting the buying process and the buying centre are presented in this chapter. These factors help to explain and predict organizational buying behaviour. The following four groups of factors have been proposed by Webster and Wind [42]:

- Environmental factors
- Organizational factors
- Interpersonal factors
- Individual factors

Wind and Thomas [50], added two groups of factors to the model presented by Webster and Wind:

- Inter-organizational factors
- Buying situation
Environmental Factors

Environmental factors are, to the buying organization, external factors such as physical, technical, economic, political, legal, and social factors. These are often difficult to identify and measure and can be seen as, to an organization, uncontrollable constraints affecting its buying behaviour. Nonetheless, "marketing strategies aimed at organizational buyers must be sensitive to these very important environmental influences because they define the boundaries within which the buyer-seller relationship must be developed" [42].

Physical factors are for example the geographical location of the organization defining its nearness to raw material, labour and transportation. Another physical factor, that is sure to affect the decisions made by an organization, is the ecological consequences (implicitly also legal, political… consequences) due to the organization's activity on the physical environment.

Price and wage conditions, the availability of money and credit, the strength of demand are among the most important economic factors. Political influences include trade agreements among nations, lobbying activities and government funding of certain buying activities. Legal influence may be government regulations used to determine specifications for what is bought as well as the terms of sale. Social factors are the culture, values, customs, habits, norms and traditions etc. that characterise a society [Ibid].

Organizational Factors

Each company has its own objectives, policies, procedures, structure and systems, and it is important for a marketer to understand these factors well. According to Sheth [54], there are three organization-specific factors, company size, company orientation and degree of centralisation. A technology-oriented company is likely to be dominated by engineering people making most buying decisions. In the same way, production personnel will make the buying decisions in a production-oriented company. Decision making in large corporations and companies with a high degree of centralisation tends to be joint.

Interpersonal Factors

The buying centre normally includes several members influencing each other. A participant may influence the buying decision because he or she holds the highest rank. This person is however not necessarily the most influential. Influence can be exerted by participants because they are
liked, have the power to reward and / or punish. One person in the buying centre that is
important to identify is the one who is considered to be the local expert. The most powerful
managers are usually influenced by those whose power is based on expertise [59].

**Individual Factors**

Members in the buying centre influence the decision process with their own preferences,
perceptions and motivation. These individual factors are affected by personal characteristics such
as, age, education, job position and personality [45].

**Inter-Organizational Factors**

Wind and Thomas [50], present Evan's model to describe inter-organizational relations: the inter-
organizational set approach. This model consists of a focal organization set, which represents
the buying organization, in our study the steelwork. There is an input organizational set, such as
suppliers and finally, there is the output organizational set, which is represented by the customers,
retailers etc.

![Figure 3-7](#) Schematic representation of the inter-organizational set approach [50].

Campbell [60] classifies different types of buyer-seller relationships, existing in different types of
markets: perfect, seller’s, domesticated, captive, buyer’s and subcontract markets. These different types of
correspond with different marketing and purchasing strategies: competitive, cooperative and command
strategies. Campbell illustrates these different market structures in Figure 3-8.

<table>
<thead>
<tr>
<th>Purchasing Strategies</th>
<th>Competitive</th>
<th>Marketing Strategies</th>
<th>Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>Command</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Competitive</td>
<td>Cooperative</td>
<td>Command</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Independent</td>
<td>Mismatch</td>
<td>Seller’s Market</td>
</tr>
<tr>
<td></td>
<td>Perfect Market</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Mismatch</td>
<td>Interdependent</td>
<td>Dependent</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Independent</td>
<td>Dependent</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Buyer’s Market</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Domesticated Market</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Captive Market</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>Subcontract Market</td>
<td></td>
</tr>
</tbody>
</table>

![Figure 3-8](#) Classification of buyer-seller relationships [60].
Webster [61] has described the *buyer-seller relationship* by what he calls “*the range of marketing relationship*”. In reality a continuum, the scale ranges from pure transactions at one end to fully integrated hierarchical firms at the other. This is illustrated in Figure 3-9.

1. Transactions
2. Repeated Transactions
3. Long-Term Relationships
4. Buyer-Seller Partnerships (Mutual, total dependence)
5. Strategic Alliances (Inc. joint ventures)
6. Network Organizations
7. Vertical Integration

*Figure 3-9 The Range of Marketing Relationships [61].*

**Product Specific Factors**

*Monetary value* of the product can give an idea of the grade of influence of high ranked managers. In small organizations the purchasing manager has little influence in most purchases, as the monetary value is relatively large, making top management involved. In medium-size companies the purchasing manager is delegated more responsibility as the relative size of each purchase decreases. In large companies the purchasing decisions become compartmentalised, making the purchasing managers specialists [62].

**Buying Situation**

As mentioned in paragraph 3.3.2.1, there are three factors that determine the buying situation, or *buyclass*, for a specific purchase: the newness of the problem, the information requirements and the consideration of new alternatives.
3.4. Frame of Reference

Based on the research problem stated in chapter 5.2 and the theory described in chapter 5.3, a frame of reference has been selected for this study. The research problem was:

How can the industrial buying behaviour of steel companies in Western Europe be characterized when buying roll-lines?

According to Wind and Thomas [50]: “The subset of academic studies which is directly concerned with a better understanding of organizational buying behaviour can be classified as falling into one of three areas:

1. the buying centre (the least studied area),
2. the organizational buying process, or
3. the factors affecting the organizational buying centre and process.”

Hence, the research problem was interpreted in the following research questions:

Research question 1: **How can the buying process of steel companies in Western Europe be characterized when buying roll-lines?**

Research question 2: **How can the buying centre of steel companies in Western Europe be characterized when buying roll-lines?**

Research question 3: **Which are the most influential factors affecting the buying process and the buying centre in steel companies in Western Europe when they are buying roll-lines?**

3.4.1. Industrial Buying Behaviour

The buying process will be based on the buygrid framework (cf. paragraph 3.3.2.1), which has been widely used since its introduction. Focus will lie on observing the content and number of successive decisions made in the buying centre (cf. Table 3-3).

The buying centre will be characterised by its dimensions, roles and the grade of influence of its different members (cf. Table 3-4). Factors affecting the buying centre and the buying process that will be observed are presented in Table 3-5.
### Table 3-3 Conceptualisation of the factors affecting the buying process.

<table>
<thead>
<tr>
<th>Conceptual Area</th>
<th>Concept</th>
<th>Conceptualisation</th>
<th>Measure Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buying Process</td>
<td>Buying Process</td>
<td>A process with several steps or phases that a company goes through when purchasing, based on the buygrid framework</td>
<td>Description of the content and number of successive decisions made in the buying centre.</td>
</tr>
</tbody>
</table>

### Table 3-4 Conceptualisation of the factors affecting the buying centre.

<table>
<thead>
<tr>
<th>Conceptual Area</th>
<th>Concept</th>
<th>Conceptualisation</th>
<th>Measure Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions of the buying centre</td>
<td>Vertical Involvement</td>
<td>The number of levels of the organization's authority hierarchy exerting influence and communication within the buying centre.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lateral Involvement</td>
<td>The number of the different departments and divisions involved in the buying centre.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Extensivity</td>
<td>The total number of individuals involved in the buying process.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Connectedness</td>
<td>The degree to which the members of the buying centre are linked to each other by directly communications concerning the purchase.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Centrality</td>
<td>How central the most influential person(s) is (are) in the communication network.</td>
<td></td>
</tr>
<tr>
<td>Roles in the buying centre</td>
<td>Initiator</td>
<td>Initiates the buying process.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decider</td>
<td>Makes the (formal) decisions (yes or no) concerning vendor and product.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Influencers</td>
<td>All those within and outside the organization who &quot;have a say&quot; concerning the purchase.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Purchasers</td>
<td>Obtains the product</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gatekeeper</td>
<td>Controls information (and might even control vendors access) to decision makers.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>User</td>
<td>The actual user of the product.</td>
<td></td>
</tr>
<tr>
<td>Influence in the buying centre</td>
<td>The formal or informal power of a person to affect others or outcomes in buying situations, whether or not exerted consciously.</td>
<td>Identification of the most influential members in the buying centre during the different steps of the buying process (based on the respondents’ perception).</td>
<td></td>
</tr>
</tbody>
</table>
3.4.1.1. Factors Affecting the Buying Process and the Buying Centre

**Environmental Factors**
Cultural differences between countries might affect the IBB of the companies involved in this study. Cultural influence is difficult to measure but must be taken in consideration when analysing the results. Legislative influence will be measured in terms of environmental restrictions put on the companies.

**Organizational Factors**
The size of a company has shown to have an effect on the buying behaviour [54]. In this study the number of employees and annual production will measure company size.

Orientation is another factor that will be used to distinguish differences between the steel companies examined in this study. By orientation we mean the different kinds of steel grades produced and the applied maintenance strategy. Depending on the type of steel produced, important parameters in the caster affecting roll life is changed such as temperature, mould powder etc.

**Inter-organizational Factors**
Market structure is an important factor in order to understand the supply chain for roll-lines and to identify competitors. It is also of value to know the relationship between the steelwork and other actors on the market, such as subcontractors providing roll-lines and OEMs. If a steelwork for example already has a long-term agreement with an OEM, it might be hard making the steelwork to take new offers from other actors in consideration.
**Other Product Specific Factors**
Monetary value of the product has an influence on the vertical involvement in the buying centre. Its influence will be measured as a member of the buying centres authority to realize a purchase depending on its value.

**Buying situation**
As mentioned in paragraph 3.3.2.1, there are three factors that determine the buying situation (or *buyclass*) for a specific purchase: the newness of the problem, the information requirements and the consideration of new alternatives. The possible different buying situations are defined as described in Table 3-1.
3.5. Methodology

In this chapter we will discuss the methodology used in this study.

3.5.1. Research Purpose and Approach

According to Marshall and Rossman [63] there are three major purposes of research:

- Exploration
- Description
- Explanation

Three different methods can be derived from the corresponding purposes [64]. The choice of method depends on how well the problem is defined. These methods are:

- Exploratory Research: Initial research conducted in order to clarify and define the nature of a problem.
- Descriptive Research: Research designed to describe the characteristics of a phenomenon or a population.
- Explanatory Research: Research conducted to identify cause-and-effect relationships among variables.

We want to study the industrial buying behaviour of steel companies in Western Europe when they are buying roll-lines. Considering the research problem and the research questions, the purpose of this study can be qualified mainly as descriptive. The purpose might also be termed exploratory, since we will have to be very open to any new information on the subject we study.

Reasoning can be inductive or deductive. The former implies that the researcher uses logical reasoning to establish a general proposition, which is based on empirical data; particular facts or phenomena based in reality. The latter implies abstract logical reasoning, based on something known to be true or on a known premise and leading to a conclusion. In this study we do not strive to establish a general proposition, we will only try to draw a conclusion from our findings. Hence our reasoning will be deductive.

All research can also be qualified as quantitative or qualitative. The former belongs mainly to the area of natural science, the latter to the area of social science. In this case we will use the qualitative method. Its analytical process is hermeneutic¹ and emphasis is given to description and discovery.

The study propositions [65] or set of hypotheses used in this study are those found in the Frame of Reference (cf. paragraph 3.4). This contains a series of propositions on industrial buying behaviour and more specifically on the factors affecting the buying process and the buying centre.

3.5.2. Research Strategy

In the social sciences there are five major research strategies: experiments, surveys, archival studies, histories and case studies [65]. An overview of these strategies is given in Table 3-6.

¹ A hermeneutical process is based on interpretation and understanding of a social event.
In order to choose the appropriate research strategy one must consider the following conditions:

1. The type of research question posed.
2. The extent of control an investigator has over actual behavioural events.
3. The degree of focus on contemporary as opposed to historical events.

Considering the first condition, our research questions are formulated in terms of "How" and they are mainly of exploratory nature. This narrows down our choice of strategy to Survey and Case Study and Experiment. Concerning the second condition, we do not have any control over actual behavioural events. This eliminates Experiment as a research strategy. Regarding the third condition, we focus on contemporary events. This still leaves us with Case Study and Survey as possible research strategies. We believe that the holistic view of the situation and the detailed information needed to answer our research questions (cf. paragraph 3.4) will be difficult to obtain by a Survey. This is why we choose to make a Case Study.

### 3.5.3. Sample Selection

For commercial reasons, which will not be discussed here, we were limited to steelworks casting slabs. Apart from this, the sampling in our study involved two stages:

1. The selection of the region.
2. The selection of the steelworks.

Regarding the selection of the region of Western Europe, the sampling is purposive-judgemental [66] and based on the following criteria:

- Studying steelworks in Western Europe will reduce the influence of environmental factors, such as economical and cultural differences.
- The significance of Western Europe as a market for SKF.
- The relatively advanced means of production in Western European steelworks should make them receptive to SKF’s product (i.e. ConRo).
The selection of the steelworks was also *purposive-judgemental* [Ibid.] and the following criteria were taken into consideration:

- Among the samples both actual and potential customers should be represented.
- Among the customers, we wanted to compare those who quickly had bought the product with those who had been more reluctant.
- The steelworks should belong to different groups, so as to eliminate external influences (from e.g. group-wide coordinated purchasing).

After consultation with sales people at SKF, the four steelworks presented in Table 3-7 were chosen:

### Table 3-7: Selection of steelworks included in the study

<table>
<thead>
<tr>
<th>Plant Name</th>
<th>Group</th>
<th>Location</th>
<th>Country</th>
<th>Customer status</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td></td>
<td></td>
<td>Finland</td>
<td>Well established</td>
<td>1 CCM</td>
</tr>
<tr>
<td>Case 2</td>
<td></td>
<td></td>
<td>Finland</td>
<td>Well established</td>
<td>3 CCM</td>
</tr>
<tr>
<td>Case 3</td>
<td></td>
<td></td>
<td>Sweden</td>
<td>Reluctant customer</td>
<td>2 CCM</td>
</tr>
<tr>
<td>Case 4</td>
<td></td>
<td></td>
<td>Germany</td>
<td>Not customer</td>
<td>3 CCM</td>
</tr>
</tbody>
</table>

#### 3.5.3.1. Selection of Respondents

In order to get a good overview of the company's buying behaviour, we wanted to interview people at different levels and at different departments. Accordingly, data was collected through personal interviews with people from production, maintenance, purchasing and intermediate level management.

They would have different experience and influencing factors. We assumed they would provide us with different perspectives on the company's buying behaviour. The respondents were selected after consultation with SKF sales people and with people at the steelwork.

#### 3.5.4. Data Collection

Data was collected from the following sources:

- *Scientific articles*
- *Different company websites*
- *Personal interviews* with people at the steelworks

The *interview guides* (cf. Appendix IV) were designed in cooperation with our supervisor at University of Technology and people at SKF Marketing/Development Centre in Gothenburg.

Data can be classified as *primary data* or *secondary data* [66]. Primary data is all data collected directly by the researcher for the purpose of the study. The collection of primary data is often more time consuming than the collection of secondary data. On the other hand, the primary data is by its nature well "adapted" for the study. Primary data can be either collected by *observation* or by *query*
techniques. There are three different kinds of query techniques: surveys, personal interviews and telephone interviews.

In our case we have used both primary data collected by query techniques (the survey and the personal interviews) and secondary data (scientific articles and company websites). It would have been easier to use only secondary data, but all the information we needed was not available as such.

3.5.5. Validity and Reliability

If the validity is good, the findings really are what they appear to be, if the correct objects have been measured [66]. In other words, the validity is a measure of the absence of systematic measure errors. Internal validity shows if the measuring instruments have been used correctly and if accurate theories have been used. External validity concerns the answers; whether they are trustworthy or not.

When the reliability of the measures is high, other researcher should come to the same conclusions when conducting the observation at another time [66]. This means that the reliability is a measure of the absence of random measure errors. The purpose is to get high reliability, invariable results that is.

Ensuring the Validity

Companies and respondents were carefully selected as described in paragraph 3.5.3 and 3.5.3.1. The interview guides were reviewed by our tutor at Luleå University of Technology and by several people at SKF Marketing/Development Centre, to ensure that they were easy to understand and that a correct terminology was used. The respondents were given a guide to the areas the interview would cover beforehand, and had the opportunity to review the compiled answers afterwards.

Ensuring the Reliability

The interviews were conducted in a calm environment. The interviews were recorded and notes were taken by both authors to minimize data loss. To further secure data accuracy, a detailed compilation was made as soon as possible after the completion of each interview.
3.6. Case Studies

3.6.1. Introduction

The case studies have been carried out at four different steelworks.

Only one steelworks is buying all rolls while the other three are to more or less extent producing the rolls themselves. Data was collected through personal interviews with people from production, maintenance, purchasing and intermediate level management. As mentioned previously, the selected steelworks were:

- Case 1
- Case 2,
- Case 3
- Case 4,

3.6.2. Case 1

3.6.2.1. Background

3.6.2.2. Buying Process and Buying Centre

After a product presentation by another company, Case 1, Case 1 decided to test a product. A group consisting of a senior project leader from the purchasing department and a work planner from the maintenance department are directing tests of new rolls. A fifth member from the maintenance department might also be included in the group for technical expertise.

An offer is taken in and the other company is invited to discuss the test in more detail. A contract is written for how long the rolls will last. For rolls in the top zone this is somewhere between 100 000 – 200 000 tons. The contract is designed by the purchaser and the senior project leader.

The performance of the rolls is measured in terms of surface wear. At the end of the test, the life cycle cost of the test rolls is compared with the rolls used otherwise to see if a change to the new model would be of interest. The buying process at Case 1, Case 1 is presented in Table 3-8.

Case 1 is the only steelworks in the study that is buying all casting rolls. The company is the main provider of new rolls and is also performing repair and rework of older rolls.
### Table 3-8 Buying process at Case 1, Case 1

<table>
<thead>
<tr>
<th>Step in the buy-phase model</th>
<th>Description</th>
<th>Carried out by</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Recognition of a need</td>
<td>Need to evaluate cost effectiveness of current roll solution</td>
<td>Senior project leader, steelworks director, purchaser, work planner</td>
</tr>
<tr>
<td>2. Discovery of a new product on the market</td>
<td>Product presentation by external company</td>
<td>Presentation held for a large group of people at the steelworks</td>
</tr>
<tr>
<td>3. Determination of characteristics and quantity of a needed item</td>
<td>Smaller quantity for a test</td>
<td>Senior project leader, work planner, technician</td>
</tr>
<tr>
<td>4. Description of characteristics and quantity of a needed item</td>
<td>Might be a certain model from a certain supplier.</td>
<td>Senior project leader, work planner, technician</td>
</tr>
<tr>
<td>5. Acquisition of proposal</td>
<td>Offer taken in from the company with the new product</td>
<td>Senior project leader, steelworks director, purchaser, work planner</td>
</tr>
<tr>
<td>6. Evaluation of proposal</td>
<td>Offer discussed with the potential supplier</td>
<td>Senior project leader, steelworks director, purchaser, work planner, technician</td>
</tr>
<tr>
<td>7. Approval of the purchase</td>
<td></td>
<td>Steelworks manager</td>
</tr>
<tr>
<td>8. Selection of an order routine</td>
<td>Contract written</td>
<td>Senior project leader, purchaser, work planner</td>
</tr>
<tr>
<td>9. Performance of feedback and evaluation</td>
<td>Life cycle cost of test rolls and old rolls compared</td>
<td>Senior project leader, steelworks director, purchaser, work planner</td>
</tr>
</tbody>
</table>

3.6.2.3. Factors Affecting the Buying Process and the Buying Centre

Service-life and life cycle cost are influential factors when purchasing casting rolls. Other important factors are the relation with its current provider of casting rolls and the geographic location, size.

### 3.6.3. Case 2

#### 3.6.3.1. Background
3.6.3.2. Buying Process and Buying Centre

At Case 2 they produce and repair the roll-lines themselves. The Workshop does the welding. An external company handles the rest of the maintenance: the assembly/disassembly of the roll-lines, the turning of the rolls and the refurbishing of the housings and bearings. Case 2 has bought rolls and roll-lines from other companies, including SKF, to see if these are better.

There is an informal "Segment / Roll Team" at the Maintenance Department working continuously with roll-line development. It consists of the Workshop Manager, a Development Engineer for Maintenance and a Workshop Work Planner. Usually they are the ones initiating a purchase. Their goals are to increase operating reliability, product quality and production capacity and to reduce maintenance costs of the segments (including the roll-lines). The Workshop Manager seems to be a key person. The Roll Team discusses with the Production Department, which owns the continuous casting machines and will be paying for the new equipment in the end (because they pay and who will be paying for the new equipment in the end (since they pay the Workshop for doing the maintenance).

The Technical Purchaser at the Purchasing Department may be involved in the search for qualified suppliers, but often this is done by the Roll Team, or just by the Workshop Manager. The technical evaluation of the proposals is always done by the Roll Team together with the Production Department.

The Technical Purchaser is the one who writes a purchasing proposal. In the purchasing proposal the alternative solutions are discussed, a price comparison is done, the life cycle cost estimated and if necessary a technical comparison is done (written together with people from the Maintenance and maybe Production department).

The purchasing proposal is sent to the Maintenance Manager of the Case 2, plant. He will approve or disprove the purchase. If the sum is bigger than his right of approval, he will send the purchasing proposal to his superior, the Maintenance Director of Case 2 (who is stationed in ), who approves or disapproves the purchase. And so on. The technical purchaser purchases the equipment. The evaluation of the product in use is done by the Maintenance Department (the Toll Team). They will also talk to the Production department. The buying process is presented in Table 3-9.
Table 3-9 Buying process at Case 2,

<table>
<thead>
<tr>
<th>Step in the buy-phase model</th>
<th>Description</th>
<th>Carried out by</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Recognition of a need and a general solution or of a possible improvement</td>
<td>Wish to test new roll-lines or a roll-line component.</td>
<td>Usually the &quot;Roll Team&quot;, especially the Workshop Manager, occasionally the Production department.</td>
</tr>
<tr>
<td>2. Determination of characteristics and quantity of a needed item</td>
<td>A small quantity for a test. Might be a certain model from a certain supplier.</td>
<td>The Roll Team, but they discuss with Production department.</td>
</tr>
<tr>
<td>3. Search for and qualification of potential sources</td>
<td>Manufacturer or retailer of the product.</td>
<td>- The Workshop Manager. - The whole Roll Team - The Technical Purchaser responsible for purchasing roll-line components.</td>
</tr>
<tr>
<td>4. Acquisition of proposals</td>
<td>Preferably at least three possible suppliers are searched for.</td>
<td>The Technical Purchaser and the Roll Team.</td>
</tr>
<tr>
<td>7. Approval of purchase</td>
<td>By superior in the hierarchy.</td>
<td>The Workshop Manager, maybe the Maintenance Manager of the plant and maybe the Director of Maintenance of Case 2</td>
</tr>
<tr>
<td>8. Selection of an order routine</td>
<td>The technical purchaser carries out the purchase</td>
<td>Technical Purchaser</td>
</tr>
<tr>
<td>9. Performance of feedback and evaluation</td>
<td>Evaluation of the performance of the new model compared to the ones currently in use.</td>
<td>The Roll Team / personnel of the Workshop and the Production department.</td>
</tr>
</tbody>
</table>
3.6.3.3. Factors Affecting the Buying Process and the Buying Centre

At Case 2 there are several factors affecting the buying process and the buying centre. These are: The service-life, life-cycle cost, the geographical location of the plant, the number of breakouts, the investments made in for manufacturing and repairing roll-lines, the relationship with the supplier and the relationship with other steelworks in Europe.

3.6.4. Case 3

3.6.4.1. Background

3.6.4.2. Buying Process and Buying Centre

The production and maintenance of continuous casting roll-lines is done by the Workshop of the plant. New types of welding material, bearings, housings and even rolls from other companies are tested from time to time. The Continuous Casting Machine Manager (one for each machine) discusses with the personnel of the Workshop working with the continuous casting rolls, especially the two Work Planners and the Welding Manager. The operators of the continuous caster also give feedback to their Manager.

It is the Continuous Casting Machine Manager who usually takes the initiative to issue a test order, even though the idea might have come from the above-mentioned persons. He will contact a Purchaser of the purchasing department. There is one purchaser, responsible for nondurable capital goods (e.g. bearings) and another, responsible for investments. In the case of a small test order of continuous casting roll-lines, it is probably the former who will be involved. The Casting Machine Manager and/or the Purchaser will look for suppliers. The negotiation with the supplier may also be carried out by either of them, since this is a just a small test order. The purchaser will make the actual purchase.

Bigger purchases must be approved by a superior. The Plant Manager may approve purchases up to a certain sum, then it is the CEO and the board of Case 3 who approves the purchase.
Table 3-10 Buying process at Case 3.

<table>
<thead>
<tr>
<th>Step in the buy-phase model</th>
<th>Description</th>
<th>Carried out by</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Recognition of a need and a general solution or of a possible improvement</td>
<td>Wish to test a new type of roll-line or roll-line component.</td>
<td>Continuous Casting Machine Manager after discussion with Workshop and Production personnel.</td>
</tr>
<tr>
<td>2. Determination of characteristics and quantity of a needed item</td>
<td>A small quantity for a test.</td>
<td>Continuous Casting Machine Manager after discussion with Workshop and Production personnel.</td>
</tr>
<tr>
<td>3. Description of characteristics and quantity of a needed item</td>
<td>Might be a certain model from a certain supplier.</td>
<td>Continuous Casting Machine Manager.</td>
</tr>
<tr>
<td>4. Search for and qualification of potential sources</td>
<td>Manufacturer or retailer of the product.</td>
<td>Continuous Casting Machine Manager or Purchaser.</td>
</tr>
<tr>
<td>5. Acquisition and analysis of proposals</td>
<td>Preferably at least three possible suppliers are searched for.</td>
<td>Continuous Casting Machine Manager or Purchaser.</td>
</tr>
<tr>
<td>7. Approval of the purchase</td>
<td>By superior in the hierarchy.</td>
<td>Steelworks manager</td>
</tr>
<tr>
<td>8. Selection of an order routine</td>
<td>The purchaser carries out the purchase</td>
<td>Technical Purchaser</td>
</tr>
</tbody>
</table>

3.6.4.3. Factors Affecting the Buying Process and the Buying Centre

At Case 3 there are several factors affecting the buying process and the buying centre. These are: Service-life, life cycle cost, the geographical location, the production volume, the number of breakouts, the relationship with the supplier and the relationship with other steelworks in Europe.

3.6.5. Case 4
Casting rolls are considered a core competence. Therefore all rolls are made and repaired at their own maintenance workshop and there are no plans at Case 4 on outsourcing manufacturing or repairing of casting rolls. No information regarding the purchase of casting rolls was obtained during the interview. Therefore, Case 4 will not be included in the analysis.
3.7. Analysis

3.7.1. Introduction
In this chapter the results from the case studies are analysed and the results are discussed. The analysis is divided into within-case analysis and cross-case analysis. The within-case analysis consists of comparing each case with the frame of reference and in the cross-case analysis the cases are compared with one another.

3.7.2. Within-Case Analysis

3.7.2.1. Important Remark
We found that in case 1-3, no purchase of roll-lines would ever be made without first making a test. This test consists of placing an order of a few rolls. These rolls are placed in the machine and their performance during service is evaluated. Only if the outcome of the test is positive, the company may choose to place a big order. Even though the test order has relatively low economic value, compared to a full scale order, it is during this process that the relationships are established between the buying and the selling company. For these reasons we have chosen to investigate the industrial buying behaviour during a test order of roll-lines.

3.7.2.2. Buying Process
In chapter 3.3.2.1 the buygrid framework was presented. The buygrid identifies eight different steps in the buying process and the within-case study has been performed with regard to these eight steps. In Table 3-11 the buying process at the three steelworks are compared with the buygrid model.

Case 1,
The buying process at Case 1 follows the buy grid model rather well. Step four is not performed at Case 1 as they wanted to test a product only provided by a specific company. Step six is divided into two parts where the first part is performed mainly by the Senior Project Manager and the Work Planner and Technician from the maintenance department. The second part, the approval, is done given by the steelworks manager.

Case 2
At Case 2, the first five steps in the buying process follows the buy grid model. The sixth step is divided into three parts where the roll team participate more in the first part than in the second where the technical purchaser is more involved. The third part, approval of purchase is carried out by the maintenance manager or the maintenance director.

Case 3,
The buying process at Case 3, follows the buy grid model very well, no significant difference is observed. Like Case 1, Case 1, step six is divided into two parts where the first part is performed mainly by the Continuous Casting Machine Manager and Purchaser. The second part, the approval, is performed by the steelworks manager.
Table 3-11 Buying process at the three different steelworks compared with buygrid model.

<table>
<thead>
<tr>
<th>Buygrid Model</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Anticipation or recognition of a problem and a general solution</td>
<td>Recognition of a need</td>
<td>Recognition of a need and a general solution or of a possible improvement</td>
<td>Recognition of a need and a general solution or of a possible improvement</td>
</tr>
<tr>
<td></td>
<td>Discovery of a new product on the market</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Determination of characteristics and quantity of a needed item</td>
<td>Determination of characteristics and quantity of a needed item</td>
<td>Determination of characteristics and quantity of a needed item</td>
<td>Determination of characteristics and quantity of a needed item</td>
</tr>
<tr>
<td>3. Description of characteristics and quantity of a needed item</td>
<td>Description of characteristics and quantity of a needed item</td>
<td>Description of characteristics and quantity of a needed item</td>
<td>Description of characteristics and quantity of a needed item</td>
</tr>
<tr>
<td>4. Search for and qualification of potential sources</td>
<td>-</td>
<td>Search for and qualification of potential sources</td>
<td>Search for and qualification of potential sources</td>
</tr>
<tr>
<td>5. Acquisition and analysis of proposals</td>
<td>Acquisition of proposal</td>
<td>Acquisition of proposals</td>
<td>Acquisition and analysis of proposals</td>
</tr>
<tr>
<td>6. Evaluation of proposals and selection of supplier(s)</td>
<td>Evaluation of proposals and selection of supplier(s)</td>
<td>Analysis and evaluation of proposals</td>
<td>Evaluation of proposals and selection of supplier(s)</td>
</tr>
<tr>
<td></td>
<td>Approval of the purchase</td>
<td>Selection of a supplier</td>
<td>Approval of the purchase</td>
</tr>
<tr>
<td>7. Selection of an order routine</td>
<td>Selection of an order routine</td>
<td>Selection of an order routine</td>
<td>Selection of an order routine</td>
</tr>
<tr>
<td>8. Performance of feedback and evaluation</td>
<td>Performance of feedback and evaluation</td>
<td>Performance of feedback and evaluation</td>
<td>Performance of feedback and evaluation</td>
</tr>
</tbody>
</table>
### 3.7.2.3. Buying Centre

The buying centre can be divided into three areas; the dimensions of the buying centre, the roles in the buying centre and the influence in the buying centre.

**Dimensions in the Buying Centre**

The data collected concerning the dimensions in the buying centre are shown in table Table 3-12.

<table>
<thead>
<tr>
<th>Dimensions in the Buying Centre</th>
<th>Measure used</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vertical Involvement</strong></td>
<td>The number of levels of the organisation's hierarchy exerting influence in the buying centre</td>
<td>3-4 Steelworks Manager, Senior Project Leader, Work Planner Maintenance Department, Technician Maintenance Department</td>
<td>3-4 Maintenance Manager, Workshop Manager, Work Planner Maintenance Department</td>
<td>3-4 Steelworks Manager, CCM Manager, Technician</td>
</tr>
<tr>
<td><strong>Lateral Involvement</strong></td>
<td>The number of the different departments involved in the buying centre</td>
<td>4 Top Management, Project Management, Maintenance, Purchasing</td>
<td>3-4 Top Management, Maintenance, Production, Purchasing</td>
<td>4 Top Management, Maintenance, Production, Purchasing</td>
</tr>
<tr>
<td><strong>Extensivity</strong></td>
<td>The total number of individuals involved in the buying process</td>
<td>4-5</td>
<td>5-6</td>
<td>6</td>
</tr>
<tr>
<td><strong>Connectedness</strong></td>
<td>The degree to which the members of the buying centre are linked to each other by direct communications</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Centrality</strong></td>
<td>How central the most influential person(s) is (are) in the communication network.</td>
<td>The senior project leader is the most influential and he has a very central role</td>
<td>The members of the Roll Team are the most influential and they have a very central position, especially the Workshop Manager.</td>
<td>The CCM Manager is the most influential person and he has a central role.</td>
</tr>
</tbody>
</table>
Industrial Buying Behaviour Study – Analysis

Case 1
The size of the buying centre increases with the value of the purchase, approval from higher levels is required. The lateral involvement is not affected by the value of the purchase. The project group consisting of Senior Project Leader, Steelworks Manager, Work Planner and Technician from the maintenance department and Purchaser handles basically everything. The senior project leader is the most influential and he has a very central role.

Case 2
A test consists only of a few rolls. The value of a test rarely exceeds the limit so that approval from the maintenance director is necessary. The lateral involvement is not affected by the value of the purchase. The members of the Roll Team are the most influential and they have a very central position, especially the Workshop Manager.

Case 3
The value of a roll test rarely exceeds the limit so that approval from top management is required. The lateral influence is not affected by the value of the purchase. The connectedness is high during all stages. The CCM Manager is the most influential person and he has a central role.

Roles in the Buying Centre
The data concerning the roles in the buying centre is presented in Table 3-13.

Case 1
The Senior Project Leader is a key person. He participates and exerts a strong influence in all steps of the buying process. The approval of the steelworks director is necessary and his role is not just purely formal as he also participate in the project group that is carrying out the

Case 2
At Case 2 the Workshop Manager is the most central person in the buying centre. He plays the role of initiator as well as Gatekeeper, Influencer and User. Other heavy Influencers are the production engineer and the other members of the roll team: a Development Engineer at the Maintenance Department, and a Workshop Work Planner.

The Technical Purchaser of the Purchasing Department is Purchaser and may also act as Gatekeeper in the case when he is the one searching for suppliers and when he writes the purchasing proposal. He may also influence the purchase: if there are several proposals that are equivalent technologically, he will favour the cheapest one.

The Continuous Casting Production Department and the Mechanical repair works of the Workshop and the external company doing the roll-line maintenance are the users. The Maintenance Manager of the Case 2, plant and, for big sums, the Maintenance Director of Case 2 are the Deciders. They give the formal approval after having read the purchasing proposal.

Case 3
The Continuous Casting Machine Manager is a key person. He plays all the roles, except the Purchaser. The Purchaser of the Purchasing Department plays the role of Purchaser and may be a Gatekeeper in the case that he / she is involved in the search for possible suppliers. The Mechanical Workshop Planners and Welding Manager are heavy Influencers. The Continuous
Casting Machine operators and the welders and turners of the Mechanical Workshop may also be influencers. There is an Engineer of the R&D working among other things with the development of the roll-lines; he may be an initiator, but will probably only act as an influencer.

Table 3-13 Roles in the buying centre at the three steelworks.

<table>
<thead>
<tr>
<th>Roles in the Buying Centre</th>
<th>Description</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiator</td>
<td>Initiates the buying process.</td>
<td>Senior Project Leader</td>
<td>Workshop Manager, Production Engineer</td>
<td>Continuous Casting Machine Manager, Engineer R&amp;D</td>
</tr>
<tr>
<td>Decider</td>
<td>Makes the (formal) decisions (yes or no) concerning vendor and product</td>
<td>Steelworks Manager</td>
<td>Maintenance Manager of the Case 2, plant, Maintenance Director of Case 2</td>
<td>Continuous Casting Machine Manager</td>
</tr>
<tr>
<td>Influencers</td>
<td>All those who ”have a say” concerning the purchase.</td>
<td>Senior Project Leader, Steelworks Director, Work Planner Maintenance, Technician Maintenance, Technical Purchaser</td>
<td>Workshop Manager, Workshop Planner, Development Engineer Maintenance, Production Engineer</td>
<td>Continuous Casting Machine Manager, Mechanical Workshop Planners and Welding Manager, Mechanical Workshop Welders and Turners, Continuous Casting Machine Operators, Engineer R&amp;D</td>
</tr>
<tr>
<td>Purchasers</td>
<td>Obtains the product</td>
<td>Senior Project Leader, Technical Purchaser</td>
<td>Technical Purchaser</td>
<td>Technical Purchaser</td>
</tr>
<tr>
<td>Gatekeeper</td>
<td>Controls information (and might even control vendors access) to decision makers.</td>
<td>Senior Project Leader</td>
<td>Workshop Manager, Technical Purchaser</td>
<td>Continuous Casting Machine Manager</td>
</tr>
<tr>
<td>User</td>
<td>The actual user of the product.</td>
<td>Continuous Casting Production Department, Maintenance Department</td>
<td>Continuous Casting Production Department, Workshop Mechanical repair works department, External Roll-line Maintenance Company</td>
<td>Continuous Casting Production Department, Mechanical Workshop Mechanical Repair works</td>
</tr>
</tbody>
</table>
Influence in the Buying Centre

In all cases, the purchasing department has a very small influence in the buying of casting rolls. At Case 1, Case 1 and Case 2, the maintenance department is the leading department in the purchase of casting rolls while At Case 3, it is the production department that plays a central role. Common for all cases is that top management has very little influence in the purchase. The most influential member of the buying centre at each steelwork is presented in Table 3-14.

Table 3-14 Influence in the buying centre.

<table>
<thead>
<tr>
<th>Influence in the Buying Centre</th>
<th>Measure used</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>The formal or informal power of a person to affect others or outcomes in buying situations whether or not exerted consciously.</td>
<td>Identification of the most influential member in the buying centre (based on respondents perception)</td>
<td>Senior Project Leader</td>
<td>The “Roll Team” but especially the Workshop Manager</td>
<td>The CCM Manager and Engineer R&amp;D Department</td>
</tr>
</tbody>
</table>

Case 1

The Senior Project Manager and the Maintenance Planner are the two most influential participants in the buying centre concerning casting rolls.

Case 2

The workshop manager is a welding specialist and considered as the local roll expert. Together with the other members of the “Roll Team” he is the most influential in the buying centre.

Case 3

The CCM manager was earlier maintenance manager and has a long experience of casting rolls. During his time as maintenance manager there was a “Roll Group” that used to have meetings and discuss problems and improvements of casting rolls. This group was disintegrated but it is very likely that it now will be reinitiated and more focus will be placed on casting roll matters.

3.7.2.4. Factors Affecting the Buying Process and the Buying Centre

The data collected have been compared with the five groups of factors discussed in the frame of reference. The results are presented in Table 3-15.

Case 1

The geographic location of a supplier is important, the closer the better.

A company provides Case 1 with new rolls and performs repair of used rolls. They are very satisfied with the cooperation.
In terms of annual production, Case 1 is the smallest steelworks in the study. The need for repair and manufacturing of rolls at a small steelworks may not be sufficient to motivate the purchase of equipment to carry out these operations. At Case 1, the production and repair of rolls is not considered to be a core competence.

Two other very important factors are the service life and the life cycle cost of the rolls. Buying rolls in kr/tons is a possibility. Service life of the rolls is connected to the functioning of the continuous caster. A stop on the continuous caster is very costly so roll service life is an important issue. However, bad process control on the continuous caster may lead to breakouts or other stops not caused by failing rolls.

Case 2

This explains partially why they are producing the rolls themselves.

Due to the fact that the service conditions for castings rolls vary from machine to machine, every steelworks has to find out what type of roll material and roll design work best for them. Case 2, is continuously evaluating their existing solutions and by talking with people at other steelworks they get many new ideas. The life cycle cost of the rolls is a very important factor.

Case 2, is a quite big steelworks and they have recently invested in new welding equipment for their workshop. The workshop manager admits that there are no plans to stop producing their own rolls.

Case 3

The geographic location is an important factor as long transports are expensive. The relation with other companies is very important for getting new ideas of how to improve the casting rolls. For example, on the recommendation of the workshop manager at Case 2, Case 3, is now using the same welding method and welding material for their rolls. The CCM manager got the idea to turn grooves into the rolls after a visit at the

Life cycle cost is a very important factor. Case 3, has the policy to never fire an employee. This makes it more complicated for them to outsource the production of casting rolls as the employees that used to do this work will need to do something else.

A common and important factor for every steelworks in this study is the number of breakouts. Frequent breakouts means that rolls near the mould will be covered in molten steel quite often, thus making sophisticated but expensive roll solutions such as the SKF ConRo less attractive.
Table 3-15 Factors affecting the buying process and the buying centre.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Measure used</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental factors</td>
<td>Cultural, political, physical and legislative factors affecting the BC and BP.</td>
<td>Geographic location</td>
<td>Geographic location</td>
<td>Geographic location</td>
</tr>
<tr>
<td>Inter-organizational</td>
<td>The most important inter-organizational determinants affecting buying behaviour.</td>
<td>Contract with other company, Unwilling to buy rolls separately in big investments, Technology exchange with other companies</td>
<td>Technology exchange with other companies</td>
<td>Technology exchange with other companies</td>
</tr>
<tr>
<td>factors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organizational factors</td>
<td>The most important organizational determinants affecting buying behaviour.</td>
<td>One CCM, Breakouts</td>
<td>Three CCMs, Recent investments in workshop capacity, Breakouts</td>
<td>Two CCMs, Breakouts</td>
</tr>
<tr>
<td>Product specific factors</td>
<td>The most important product specific determinants affecting buying behaviour.</td>
<td>Life cycle cost, Performance, Service life</td>
<td>Life cycle cost, Performance, Service life</td>
<td>Life cycle cost, Performance, Service life</td>
</tr>
<tr>
<td>Buying situation</td>
<td>The buying situation's effect on buying behaviour.</td>
<td>New task</td>
<td>New task</td>
<td>New task</td>
</tr>
</tbody>
</table>

3.7.3. Cross-Case Analysis

In the cross case analysis, differences and similarities in the buying process, buying centre and factors affecting the buying process and the buying centre between the companies are discussed and analysed.

3.7.3.1. Buying Process

Data shows that there are few differences in steps of the buying process between the different cases. The buying process at Case 1, Case 1 differs from the other two as the there is no search for several suppliers. This difference is mainly due to the fact that the information gathered at Case 1 concerned a specific purchase while the information from Case 2, and Case 3, referred to hypothetical purchase of test rolls.

3.7.3.2. Buying Centre

The extensivity of the buying centre varies between four and six members. The vertical involvement in the buying centre varies little between the different cases. The value of a roll test always requires an approval from someone high up in the organisation. At Case 3, and Case 1 it is the Steelworks Manager who approves a purchase, while at Case 2, it is the responsibility of the Maintenance Manager or (in rare cases) the Maintenance Director (who is
located in ). It is interesting to see that in the latter case, the right of approval remains within the management of the maintenance organization; while as in the former cases, the right of approval remains within the management of the steelworks.

All companies have four departments involved in the buying process and their connectedness is high. Case 1 is the only steelworks where the production department is not a part of the buying centre. In all cases the maintenance department has an important and role but is not necessarily the most influential. At Case 1, it is the Senior Project Leader who is the most central and influential member. The most influential and central member of the buying centre at Case 3, the continuous casting manager, belongs to the production department. At Case 2, however, the work shop manager of the maintenance department is the most central and influential member of the buying centre. Common for the most influential members of each steelworks is that they all have a background within maintenance. Both purchasing department and top management have little influence in the buying centre. The central role of the maintenance department is probably due to the fact that they are working with repair and manufacturing of casting rolls. In the case of Case 1, Case 1 the maintenance department only handles the changing of rolls but is still the department at the steelworks that most deals with rolls.

3.7.3.3. Factors Affecting the Buying Process and the Buying Centre

All companies have the same opinion about which factors that are important in the purchase of casting rolls for example the proximity to the supplier, service life and life cycle cost. At Case 1, the relation with their current provider of roll-lines and roll-line maintenance is a very important factor. They have a close cooperation and the proximity of the subcontractor to Case 1 is considered an advantage.

The difference in size (number of continuous casting machines) between the different production sites must not be neglected. Case 1, with only one caster, might not have enough casting rolls to motivate the build-up of own roll-line manufacturing and maintenance organisation. On the other hand, Case 2, and Case 3, with three and two casters respectively, have their own organisations for this. A good relationship between the buyer and the seller is considered vital in all cases. The seller must be perceived as trustworthy, competent and able to solve any problems in cooperation with the buyer.
3.8. Findings, Conclusions and Recommendations

3.8.1. Introduction

In this chapter the findings from the within case and cross case analysis will be discussed. The discussion is based on the research problem formulated in chapter 3.2.3: How can the industrial buying behaviour of steel companies in Western Europe be characterized when buying roll-lines?

The three areas of Industrial buying behaviour: the buying process, the buying centre and factors affecting the buying process and the buying centre, has been covered by one of the three research questions stated in chapter 3.4:

Research question 1: How can the buying process of steel companies in Western Europe be characterized when buying roll-lines?

Research question 2: How can the buying centre of steel companies in Western Europe be characterized when buying roll-lines?

Research question 3: Which are the most influential factors affecting the buying process and the buying centre in steel companies in Western Europe when they are buying roll-lines?

3.8.2. Findings and Conclusions

3.8.2.1. Findings Regarding Research Question One

Findings show that the buying process for a test order of roll-lines at steelworks in Western Europe follows mainly the buygrid model proposed by [51]. The major difference lies in the sixth step of the buygrid model which is divided into three steps at Case 2, and into two steps at Case 1 and Case 3.

3.8.2.2. Findings Regarding Research Question Two

The buying centre of steel companies in Western Europe has been investigated with respect to its dimensions, roles and influence.

Dimensions in the Buying Centre

In the three steelworks, Case 1, Case 2, and Case 3, the size or extensivity of the buying centres varied between four and six persons. The vertical involvement is almost the same in the different cases. A test order generally requires an approval from someone higher up in the organization. At Case 2, this superior was from the maintenance organization: either the Maintenance Manager of the steelworks or the Maintenance Director for Case 2, who is positioned in

In every company investigated, there were three to four departments involved in the buying process and the connectedness between these departments was high. The maintenance and the purchasing department were always involved. The production department was involved at Case
3, and Case 2, but not at Case 1, where the “Project Management” was involved instead. Finally the Plant Manager or the Maintenance Manager / Director were involved as described in the previous paragraph.

**Roles in the Buying Centre**

Depending on the case, different persons will play different roles. People from the maintenance and/or the production will play the role of *user* and also *influencer*. The initiator may be a production engineer or an R&D engineer. However, in most cases, the *initiator* is some kind of intermediate level manager (CCM manager, Maintenance Workshop manager, Project Manager). This person may also play the roles of *gatekeeper*, *user* and *purchaser*. His superior will be the *decider*. In general, a purchaser will play the role of *purchaser* and may also be a *gatekeeper*.

**Influence in the Buying Centre**

The maintenance department plays a pretty central role in all cases. This is probably due to the fact that the maintenance department handles the changing of the rolls and sees the effects on their service life. The intermediate level manager mentioned in the previous paragraph, is the most influential person in each buying centre. He plays several of the rolls in the buying centre, has technical competence with experience from maintenance and heads the “local expert group on rolls / segments”.

**3.8.2.3. Findings Regarding Research Question Three**

The most important factor in all cases is that the service life of the roll-lines is adapted to the specific conditions in the caster. A steelwork with bad process control and frequent breakouts will not consider using an expensive roll-line solution with a service-life longer than necessary. When an optimal solution is found the life-cycle cost and performance of the rolls are important factors.

A roll purchase is a process that reaches over a long period of time making the relationship between the buyer and the seller a very important factor.

**3.8.3. Conclusions**

Our findings show that the buy grid model is a suitable analytical tool for investigating the industrial buying behaviour of steelworks in Western Europe when purchasing roll-lines. The differences found between reality and theory concerning the buying process and the buying centre are not significant enough to suggest a change to the theories.

A number of conclusions are drawn from this study.

- A big roll-line order is always preceded by a test order.
- The decision-making power lays in the intermediate level management, even though approval is required from upper level management.
- The maintenance department always plays a central role.
- Service-life and life-cycle cost are the two most important product specific factors.
- A good relation between the buyer and the seller is vital.
- The will to outsource roll-line manufacturing and maintenance seem to decrease with the size of the steelwork.
3.8.4. Further Research and Recommendations

Many steelworks in Western Europe seem to manufacture and perform maintenance on roll-lines themselves. Before conducting any further buying behaviour studies on roll-lines, it would be interesting to investigate the factors influencing a steelworks decision to “make or buy”. Further studies, similar to this one but in other countries, would be beneficial for the comprehension of this subject. Analysing the process occurring after a test order is another highly interesting issue.
4. References

Metallurgical Study


References


Market Study


Appendices

Appendix I - Rockwell Hardness

Figure 1 Average surface hardness of roll 1 and 2 measured in different positions. The error bars represent the 95% confidence interval.
Figure 2: Hardness profile of roll 1 in the Y direction measured in different positions. Conversion from HV to HRC according to ASTM E140 – 97 standards.

Figure 3: Hardness profile of roll 2 in the Y direction measured in different positions. Conversion from HV to HRC according to ASTM E140 – 97 standards.
Appendix II - Macrostructure

Roll no. 1

Figure 4 Roll no. 1. Position AI. a) XY-plane. b) YZ-plane.

Figure 5 Roll no. 1. Position AII. a) XY-plane. b) YZ-plane.

Figure 6 Roll no. 1. Position MI. a) XY-plane.
Appendix II - Macrostructure

Figure 7 Roll no. 1. Position MII a) XY-plane. b) YZ-plane.

Roll no. 2

Figure 8 Roll no. 2. Position AI a) XY-plane. b) YZ-plane.

Figure 9 Roll no. 2. Position AII a) XY-plane. b) YZ-plane.
Figure 10 Roll no. 2. Position M1 a) XY-plane. b) YZ-plane.

Figure 11 Roll no. 2. Position MII a) XY-plane. b) YZ-plane.
Appendix III - Microstructure

Roll no. 1

Position AII bead

Figure 12 Roll no. 1. Position AII bead. Etched with Kalling Delta ferrite in martensite.

Figure 13 Roll no. 1. Position AII bead. Etched with Marble's Reagent. a) Surface, layer 3. b) Transition layer 3 – 2.

Figure 14 Roll no. 1. Position AII bead. Etched with Marble's Reagent a) Surface, layer 3 b) Transition 3 – 2.
Appendix III – Microstructure

Figure 15 Roll no. 1. Position AII bead. Etched with Marble’s Reagent a) Transition layer 2 – 1. b) Transition 1 – base material.

Figure 16 Roll no. 1. Position AII bead. Etched with Nital 1.5%. a) Transition layer 1 – base material. b) 2.0 mm below the transition layer 1 – base material.

Figure 17 Roll no. 1. Position AII bead. Etched with Nital 1.5% Base material at the inner diameter of the roll.
Appendix III – Microstructure

Position AII overlap

Figure 18 Roll no. 1. Position AII overlap. Etched with Marble’s Reagent a) Surface corrosion pit. b) Surface corrosion pit.

Figure 19 Roll no. 1. Position AII overlap. Etched with Marble’s Reagent a) Transition layer 3 – 2. b) Transition layer 2 – 1.

Figure 20 Roll no. 1. Position AII overlap. Etched with Marble’s Reagent. Transition layer 1 – base material.
Position MI bead

**Figure 21** Roll no. 1. Position MI bead. Etched with Marble’s Reagent. **a)** Microstructure at the surface. **b)** Transition layer 3 – 2.

Position MI overlap

**Figure 23** Roll no. 1. Position MI overlap. Etched with Marble’s Reagent. **a)** Transition layer 3 – 2 at the surface. **b)** Transition layer 3 - 2.
Appendix III – Microstructure

Figure 24 Roll no. 1. Position MI overlap. Etched with Marble’s Reagent. a) Transition layer 2 – 1. b) Transition layer 1 – base material.

Figure 25 Roll no. 1. Position MI overlap. No etching. a) Surface corrosion pits. b) Surface corrosion pits.

Position MII bead

Figure 26 Roll no. 1. Position MII bead. Etched with Marble’s Reagent. a) Surface. b) Transition layer 3 - 2.
Appendix III – Microstructure

Figure 27 Roll no. 1. Position MII bead. Etched with Marble’s Reagent a) Transition layer 2 – 1. b) Transition layer 1 – base material.

Figure 28 Roll no. 1. Position MII bead. Etched with Nital 1.5% a) Transition layer 1 – base material. b) In the middle of the base material.

Figure 29 Roll no. 1. Position MII bead. Etched with Nital 1.5% Base material at the inner diameter of the roll.
Position MII overlap

Figure 30 Roll no. 1. Position MII overlap. Etched with Marble’s Reagent. a) Surface corrosion pit. b) Surface corrosion pit.

Figure 31 Roll no. 1. Position MII overlap. Etched with Marble’s Reagent. a) Corrosion attacking delta ferrite. b) Delta ferrite in martensite.

Figure 32 Roll no. 1. Position MII overlap. Etched with Marble’s Reagent. a) Delta ferrite in martensite. b) Delta ferrite in martensite.
Appendix III – Microstructure

Figure 33 Roll no. 1. Position MII overlap. Etched with Marble’s Reagent. Transition layer 3 – 2.

Figure 34 Roll no. 1. Position MII overlap. Etched with Marble’s Reagent. a) Transition layer 2 – 1. b) Transition layer 1 – base material.
Roll no. 2

Position AII bead

Figure 35 Roll no. 2. Position AII bead. Etched with Marble’s Reagent. a) Surface, layer 2. b) Transition layer 2 – 1.

Figure 36 Roll no. 2. Position AII bead. Etched with Nital 1.5%. b) Layer 2. a) Layer 1 – base material.

Figure 37 Roll no. 2. Position AII bead. Etched with Nital 1.5%. a) Transition layer 1 – base material. b) Just below the transition layer 1 – base material.
Appendix III - Microstructure

Figure 38 Roll no. 2. Position AII bead. Etched with Nital 1.5%. \textbf{a)} In the middle of the base material. \textbf{b)} Base material at the inner diameter of the roll.

Figure 39 Roll no. 2. Position AII bead. No etching. \textbf{a)} Surface corrosion pits and cracking. \textbf{b)} Surface corrosion pits and cracking.

Figure 40 Roll no. 2. Position AII bead. No etching. Surface corrosion pits and cracking.
Position AII overlap

**Figure 41** Roll no. 2. Position AII overlap. Etched with Marble’s Reagent.  
**a)** Surface with corrosion attacks.  
**b)** Detail of corrosion attacking the delta ferrite network.

Position MI bead

**Figure 42** Roll no. 2. Position MI bead. Etched with Marble’s Reagent.  
**a)** Detail of the surface.  
**b)** Transition layer 2 – 1.

**Figure 43** Roll no. 2. Position MI bead. Etched with Marble’s Reagent.  
**a)** Surface, layer 2.  
**b)** Transition layer 2 – 1.
Appendix III – Microstructure

Figure 44 Roll no. 2. Position MI bead. Etched with Marble’s Reagent. Transition layer 1 – base material.

Position MI overlap

Figure 45 Roll no. 2. Position MI overlap. No etching. a) Surface corrosion pits and cracking. b) Surface corrosion pits and cracking.

Figure 46 Roll no. 2. Position MI overlap. Etched with Marble's Reagent. a) Surface with corrosion pit. b) Transition layer 2 – 1.
 Appendix III – Microstructure

Figure 47 Roll no. 2. Position MI overlap. Etched with Marble’s Reagent. Transition layer 1 – base material.

Position MII bead

Figure 48 Roll no. 2. Position MII bead. Etched with Marble’s Reagent. a) Surface with corrosion pit. b) Detail of surface corrosion pit.

Figure 49 Roll no. 2. Position MII bead. Etched with Marble’s Reagent. a) Layer 2. b) Transition layer 2 – 1.
Appendix III – Microstructure

**Figure 50** Roll no. 2. Position MII bead. Etched with Marble's Reagent. a) Layer 1. b) Transition layer 1 – base material.

**Figure 51** Roll no. 2. Position MII bead. Etched with Nital 1.5%. a) Transition layer 1 – base material. b) In the middle of the base material.

**Figure 52** Roll no. 2. Position MII bead. a) Base material at the inner diameter of the roll. Etched with Nital 1.5%. b) Hardness indentation at the transition between layer 1 (below) and the base material (above). Etched with Kalling.
**Appendix III – Microstructure**

**Figure 53** Roll no. 2. Position MII bead. Etched with Kalling.  
**a)** Surface corrosion pit and corroded delta ferrite.  
**b)** Layer 2. Inhomogeneous microstructure with delta ferrite.

**Figure 54** Roll no. 2. Position MII bead. Etched with Kalling.  
**a)** Hardness indentation at the transition between layer 2 (below) and layer 1 (above).  
**b)** Hardness indentation at the transition between layer 1 (below) and the base material (above).

**Position MII overlap**

**Figure 55** Roll no. 2. Position MII overlap. Etched with Marble’s Reagent.  
**a)** Layer 2.  
**b)** Detail of surface corrosion pit with corroded delta ferrite.
**Figure 56** Roll no. 2. Position MII overlap. Etched with Marble's Reagent. **a)** Transition layer 2 – 1. **b)** Layer 1.

**Figure 57** Roll no. 2. Position MII overlap. No etching. **a)** Surface corrosion pits. **b)** Surface corrosion pits.
Appendix IV - Interview Guides

Interview Guide - Production Engineer

Date:
Company:
Department:

Name:

Position:
Years at this position:
Years in the company:

Phone:
Fax:
E-mail:

Organization

1. How many employees does the production department have?

2. What responsibilities are connected to this department?

3. Do you have any environmental restrictions concerning the caster?

4. Is your company working with sustainability concerning the caster?

5. Is your department working with improvements? *(How? Why?)*

   a. What are your goals / drivers (reduced budget, production volume, product quality etc.)?
Buying Process & Buying Centre

6. Please describe the steps in your company's buying process when purchasing an upgrading solution for the CCM (for example new casting rolls, cooling system, lubrication system).

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7. Which departments in your company participate in one or more of the steps of the decision-making process concerning casting rolls?
Appendix IV – Interview Guides

8. Please identify in which steps of the process the different departments are involved.

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9. Concerning the purchase of said upgrading, please identify the persons who usually...

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10. How do you decide whether to do the upgrading yourself or to outsource it?

11. Who is involved in the search for qualified suppliers?

12. Which persons are involved in the evaluation of proposals and selection of a supplier?

13. How is the evaluation of product performance done?
14. How big purchases are you authorized to make?

15. How big a purchase is the decision maker authorized to make?

16. What factors are important / influential to the purchase of a CCM upgrade? (*Guidelines such as improving productivity or other...*)

**Buying Process Casting Rolls**

17. Who at this company, knows most about casting rolls? Is he/she involved in the buying process?

18. If you were to buy a roll line, would it be important with a customized solution (cooling system, cladding specification, etc.)?

**Segments and Roll Lines**


22. Would it be interesting allowing an external supplier to take a larger responsibility for rework of the roll lines?

**Roll Bodies / Roll Mantle and Cladding**

23. Who is your roll body / mantle provider?

24. Who developed roll body and roll mantle specifications?

25. Who is your cladding provider? (*Why? How?*)

27. What kind of roll-bodies / mantles and cladding do you use?

a. Design

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<th>Rotating mantle</th>
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![Diagram](image-url)
b. Cooling

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28. Are you satisfied with your current cladding material? *(Why?)*

29. Have you experienced any problem with the roll bodies or the internal cooling system? *(How? Why? How evaluated?)*
Interview Guide - Maintenance Engineer

Date:

Company:
Department:

Name:

Position:
Years at this position:
Years in the company:

Phone:
Fax:
E-mail:

Organization/General Company Strategy
1. How many employees does the maintenance department have?
2. What responsibilities are connected to this department?
3. Do you have any environmental restrictions concerning the caster?
4. Is your company working with sustainability concerning the caster?
5. Do you have a maintenance strategy regarding casting rolls, what is it?
   a. Are you working with improvements?
   b. What are your goals / drivers (reduced budget, increased service interval, etc.)?
   c. Are you focusing on each component or are you looking at the life cycle?
Buying Process & Buying Centre

6. Please describe the steps in your company's buying process when purchasing an upgrading solution for the CCM (for example new casting rolls, cooling system, lubrication system).

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**Buying Process Casting Rolls**

17. Who at this company knows most about casting rolls? Is he/she involved in the buying process?

18. If you were to buy a roll line, would it be important with a customized solution (cooling system, cladding specification, etc.)?

**Maintenance - General**

19. Do you have any kind of MRO agreement today?
   
   a. With who? (Why?)
   
   b. What products and services are included? (Why?)
   
   c. What is your opinion of the agreement? (Why?)

**Segments and Roll Lines**

20. How is your segment maintenance organized? (based on exp. or OEM rec. which criteria for removal??)


23. Where is the rework of the roll lines (welding, skim cutting) performed? (Why? How?)

24. How much of the maintenance costs can be related to planned and unplanned maintenance respectively? (Why? How? Which are the biggest costs? Why?)

25. Would it be interesting allowing an external supplier to take a larger responsibility for rework of the roll lines? (If not, why?)

**Roll Bodies / Roll Mantle and Cladding**

26. Who is your roll body / mantle provider?

27. Who developed roll body and roll mantle specifications?

28. Who is your cladding provider? (Why? How?)

30. What kind of roll-bodies / mantles and cladding do you use?

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Appendix IV - Interview Guides

b. Cooling

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31. Are you satisfied with your current cladding material? *(Why?)*

32. Have you experienced any problem with the roll bodies or the internal cooling system? *(How? Why? How evaluated?)*
Interview Guide - Manager

Date:
Company:
Department:

Name:
Position:
Years at this position:
Years with the company:

Phone:
Fax:
E-mail:

Organization
1. How many employees does this plant have?

2. What responsibilities are connected to your department?

3. Do you have any environmental restrictions concerning the caster?

4. Is your company working with sustainability concerning the caster?

5. What is the total annual production of the company?

6. What steel grades do you produce?

7. Are you planning to expand or upgrade the machine park within the next five years?

8. Are you working with improvements in the different departments? (Why? How?)
   
   d. In each department, what are the goals / drivers (reduced budget, increased service interval, etc.)? (Why? How? Is it successful?)
Buying Process & Buying Centre

9. Please describe the steps in your company's buying process when purchasing an upgrading solution for the CCM (for example new casting rolls, cooling system, lubrication system).

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<th>Action</th>
<th>Description</th>
<th>Who does it (title, name, department)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiates the purchase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Takes the decision to buy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Has the major influence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Issues the order</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Handles most of the information regarding the purchase</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13. How do you decide whether to do the upgrading yourself or to outsource it?

14. Who is involved in the search for qualified suppliers?
15. Which persons are involved in the evaluation of proposals and selection of a supplier?

16. How is the evaluation of product performance done?

17. How big purchases are you authorized to make?

18. How big purchases is the decision maker authorized to make?

**Buying Process Casting Rolls**

19. Who developed roll body / mantle and cladding specifications?

20. Who are your roll body / mantle and cladding providers? (How? What type of agreement? Why?)

21. Who at this company knows most about casting rolls? Is he/she involved in the buying process?

22. If you were to buy a roll line, would it be important with a customized solution (cooling system, cladding specification, etc.)?

**Cooperation**

23. Would it be interesting allowing an external supplier to take a larger responsibility for rework of the roll lines?

24. What factors are important / influential to the purchase of a CCM upgrade? (Guidelines such as improving productivity or other...?)

**Maintenance**

25. Do you have any kind of MRO agreement today?
   
   a. With who?
   
   b. What products are included?
   
   c. What is your opinion of the agreement?
   
   d. Where is the rework of the roll-lines performed? (What? How? Why?...)

26. Do you have a maintenance strategy regarding casting rolls, what is it?
   
   a. Are you working with improvements?
   
   b. What are your goals / drivers (reduced budget, increased service interval, etc.)?
   
   c. Are you focusing on each component or are you looking at the life cycle?

27. How is your segment maintenance organized? (based on exp. or OEM rec. which criteria for removal??)