SCHOOL OF MECHANICAL,
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Investigating the Transnet Foundry Quality System

School of Mechanical, Industrial and Aeronautical Engineering

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ABSTRACT

This research investigates Transnet's Foundry Quality System, focusing on the quality issues in the Foundry. This includes determining the total cost of quality for the business, investigating the impact of the specific defects on the productivity of the business. Two products were analysed namely, the top centre casting and the brake shoe holders.

Root cause analysis was done on each stage of the Foundry process to understand the causes of defects. Data was collected and analysed and most of the defects that occur were found to be the result of poor quality management which consequently causes low productivity and low profits. Also identified was a lack of skilled personnel in specific areas in the Foundry. Furthermore data collection as part of the quality system in the Foundry is not effectively executed and this implies that performance cannot be fully measured.

Non Compliance reports from customers were analysed and the total cost of quality was calculated to be R1 214 690.73 based on the data that was available. The impact of defects on productivity was also analysed for the financial year 2014/2015 and it was calculated to be 47% for the brake shoe holders. The target for the Foundry for the financial year was R4 048 799.30 for the actual productivity in sales amounted to R 1 915 510.60. For the top centre the estimated target for the financial year 2014/2015 was R6 271 500.00 and the actual productivity amounted to R3 305 250.00. Statistical process control charts were drawn and it was discovered that some of the machines owned by the business are not capable of producing to specification. Qualifound was identified as a framework to improve the Transnet foundry quality system.

It is recommended that top management be educated in the concept of cost of quality and its impact on business profitability and that skilled quality coordinators be appointed to facilitate continuous quality maintenance.

Declaration

I, Valentine Ngwenya declare that this research report is my own unaided work. It is submitted in partial fulfilment of the requirements for the degree of Masters of Science Industrial engineering (50/50) at the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Valentine Ngwenya

11 October 2016

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List of Definitions and Abbreviations

AFS Grains Fineness Number – Measure of the average size of grains in sand

Fines – Refers to the percentage of sand and clay content

Green strength – This describes the ability of a moulded or casted component to withstand handling, mould ejection and machining before it is completely hardened.

Compactability – This test indicates how wet or dry the green sand is and helps control most common green sand defects.

Permeability- Ability of compacted mould to allow air to pass through it.

Live Clay- Presence of active Bentonite which can readily bond.

Loss of Ignition (LOI) - Is the difference in weight before and after ignition of the sand. This test is done on incoming green sand.

1. COMPANY BACKGROUND

1.1 Transnet Foundry Background

Transnet Engineering (TE), an operating division of Transnet SOC Ltd, is the backbone of South Africa's railway industry with eight product-focused businesses, 150 depots, 7 factories and 15,000 employees countrywide (Transnet, 2015).Transnet Engineering has operations in Bloemfontein (BFX), Durban (DBN), Salt River (SLR), Uitenhage (UTH), Germiston (GMX) and Koedoespoort (KDS). This division is dedicated to in-service maintenance, repair, upgrade, conversion and manufacture of freight wagons, mainline and suburban coaches, diesel and electric locomotives, wheels, rotating machines, rolling stock equipment, castings, auxiliary equipment and services (Transnet, 2015). Transnet Engineering has 9 business units which include Rolling Stock Equipment (RSE), Wheels, Wagons, Coaches, Locomotives, Rotating Machines, Foundry, Auxiliary Equipment and Port Business.

Transnet Engineering's Foundry Business has a long history dating back 50 years. At one time, the business employed two thousand people with significant capacity to serve both the internal and external market (Transnet, 2015). The main objectives of Transnet Foundry are to cast bogies, frames, bolsters, wedges, side frames, couplers, draw gears and all the castings that are needed on the rolling stock such as locomotives, wagons and coaches. Currently, the Transnet Foundry business is being upgraded to resume its competitive role in the South African Rail Industry.

The business operates from two sites, one in Tshwane at Koedoespoort and a much larger facility in Bloemfontein. The facilities are both ISO 9001/2001 accredited (Transnet, 2015). The business has a staff complement of 500 in both facilities. The two facilities have the ability to produce any casting a customer may require. The business has expertise in casting all types of metals and these include steel, brass, copper, white metal, spheroid graphite (SG) and cast iron (CI) (Transnet, 2015).

Currently, the major clients that the Foundries business serves are Transnet Engineering's Wagon, Locomotive and Rolling Stock Equipment Business. External to Transnet, it also makes components for VAE Perway (Transnet, 2015). The business also serves a number of smaller clients such as NLPI, an Israeli company that owns and operates the Zambian railways. Apart from the railway industry, the Foundry Business serves a number of other industry sectors such as mining, automotive, and to a lesser extent marine. Currently the business will be required to produce castings for the Bombardier Transport, China South Railway and China North Railway (Transnet, 2015).

At Koedoespoort, the workshop is equipped with two energy-efficient induction furnaces and a semi-automated CT3 moulding machine for producing greensand moulds. The facility also has its own sand plant. The Koedoespoort facility is able to produce moulds from chemically bonded sand, though this is being phased out. The facility also has heat treatment ovens. In addition, the business has a full suite of equipment for fettling, shot blasting and finishing. The workshop has all necessary ancillary equipment such as cooling towers and overhead cranes (Transnet, 2015).

1.2 Problem Statement

Quality in Foundry can be defined in terms of fitness of cast material for purpose at the most economical level (Sobczak & Balcer, 2014). It is important that the finished products must meet the established specifications (Vijayaram, 2003). Customer satisfaction is derived from quality products and services (Vijayaram, 2003). Metal Casting is a global growth industry and with this growth, the global industry faces challenges related to industry perception, safety, and environment (Sobczak & Balcer, 2014).

China is the largest producer of metal casting with 42.5 million tons in 2012 and the largest issues faced by China include quality and process control (Madzivhandila, 2014). Germany focuses on process control during manufacturing rather than quality control after manufacturing as a way to reduce and eliminate defects (Madzivhandila, 2014)

There are a lot of concerns when it comes to quality issues in Foundries. In Africa especially small scale Foundries in Ghana, foundries have raised concerns with regards to reworks and defects in cast products (Andrews & Gikunoo, 2011). There are no laid down procedures for developing, documenting and controlling the entire casting process including Foundry engineering such as gating, risering, pattern design and pour temperature (Andrews & Gikunoo, 2011). The Ghana Foundry Association has been tasked to monitor the quality of products in the market (Andrews & Gikunoo, 2011). In many cases, casting defects may be discovered at the machining stage or at the assembly stage or during the use of the component and the resultant value added costs and warranty costs may sometimes be passed on to the Foundry by their customer (Alena, Marianna, & Dana, 2010).

In the South African Foundry business, the challenge has been one of closures. In 2007, twenty six foundries closed down (Industries & Directory, 2015). These closures were as a result of failing to compete successfully with countries such as China, India and Brazil (Mpanza, Nyembwe, & Nel, 2013). South Africa is not competitive when compared with these countries because of the lack of skilled personnel, the high scrap rate, the lack of a quality management system, and the lack of technology transfer (Mpanza, Nyembwe, & Nel, 2013).

The Transnet Foundry business has lost R5.45 million due to scrap in the year 2014 and they had targeted to make sales of R135 million. However the business was only able to make a profit of R116.18 million. The business had budgeted R54 million for purchasing stock (raw materials), however they spent R73 million and this left the business with a deficit of R19 million.

Currently, Transnet Foundry business is experiencing high levels of inefficiencies especially in the production facility and there are high levels of scrap produced, reworks and non-compliance reports received from customers (Transnet, 2015). Transnet Foundry is producing and selling their products at a higher price than other foundries and they are still not making profits. Internal customers in Transnet Engineering are opting to buy the castings from the Foundry's competitors because of their competitors' ability to manufacture castings to prescribed specification in the desired time (Transnet, 2015). In production at the Transnet Foundry, anticipated targets are not met, resulting in customer demands not being met and non-compliance reports being raised against the business (Transnet, 2015). African Foundries are experiencing challenges as indicated by Ghana Small Scale Foundries. To improve productivity in Transnet Foundry, all the quality issues and associated costs need to investigated and the technical know-how of the employees should be improved.

1.3 Research Question

What improvements to the quality system of the Transnet Foundry would contribute to increased productivity, throughput and profitability?

1.4 Objectives

From the problem statement, it is clear that there are challenges that are experienced in the production of castings especially in the small scale foundries that have limited technology. Casting defects can negatively affect the bottom line of a foundry. The objectives of this research are:

- To investigate the quality issues in the Transnet Foundry.
- To determine the total cost of quality for the Transnet foundry business.
- To investigate the impact of the specific defects on the productivity of the Transnet Foundry business.
- To determine the appropriate tools, frameworks and strategies that can be used to improve the quality system at the Foundry.

1.5 Limitations and delimitations of the research

This research will only consider investigating the Foundry's quality system. Only the Koedoespoort Foundry will be analysed and Bloemfontein will be exempted from the study. The study will also not analyse all the castings that are produced in the Foundry.

1.6 Scope of the Research

The scope of the study has been limited to the Transnet Foundry. The findings obtained from the research will not be compared to other Foundries due to lack of access to other Foundry businesses. There was not much documentation in South Africa about Foundry quality issues and as a result extensive literature was done to avoid this risk of reinventing the wheel.

1.7 Brief overview of Research Method

This research focused on the analysis of the quality system of the Foundry and Define, Measure, Analyse, Improve and Control (DMAIC) research methodology will be used. In the define phase, the problem and its scope are identified in addition to all the key metrics including the stakeholders. In the measure phase, a check is done on what data is available and the accuracy of the data and methods of data analysis are identified (Rever, 2016). The analyse phase identifies the root causes of the quality system problem and from the root cause analysis, the focus areas are identified (Rever, 2016). In the improve phase, checks are done on whether the correct solutions have been identified and verifications are done on the solutions to check feasibility. Pilot solutions are implemented and checks are also done to check if variations have been reduced. The control phase allows for recommendations to be implemented and a plan for implementation is identified. In addition a check on whether the results obtained are sustainable or not is undertaken. In the study conducted at the Transnet Foundry, archival records in the form of previous Foundry records, informal interviews conducted in the production line, participant observation through interaction with supervisors in the Foundry and direct observations were used as qualitative evidence in the study. Participant observations present challenges such as bias due to participant observer's manipulation of events. Direct observations were conducted at the sections of the Foundry where there were no previous records. The complete research design indicated what data was to be collected as indicated by the study's questions, its propositions and its units of analysis (Yin, 2009). The research approach indicated what was to be done after the data had been collected as indicated by the logic linking the data to the propositions and the criteria for interpreting the findings (Yin, 2009). Criteria for judging the quality of the research designs was used. The production line was observed from the start to the end and process maps. Cause and effect diagrams were used to heighten the impact of quality defects. Informal interviews were conducted with operators on the production line to deepen the authors understanding of the casting production line.

1.8 Ethics Considerations

The following ethical principles will be considered namely:

- Confidentiality and Privacy– To acknowledge that Transnet information is confidential and should be safeguarded and used only for research.
- Respect for intellectual property - This requires adequate acknowledgement of the prior publications that were used for research purposes.
- Objectivity - To avoid bias in data analysis and data interpretation.
- Falsification and fabrication - Avoiding falsifying data.
- Plagiarism – Using someone's information or intellectual property without acknowledging them.
- Legality- Obeying Transnet governance policies.
- Complying with Ethics: Ethics Clearance number MIAEC 050/15

1.9 Outline of chapters

Chapter 1 – Company Background

The chapter gives a general background of the research questions in relation to the company that is being studied. It also outlines the objectives of the study and gives a high level description of the research methodology that will be followed to answer the research question.

Chapter 2 – Literature review

Chapter 2 outlines the theory that was studied in order to answer the research question. This was done to understand what the current literature says in relation to the research question. An overview of the Foundry industry and its processes was analysed. This chapter aims to understand what other researchers have concluded in their studies and to check whether the same conclusions are applicable at the particular Foundry that is currently being studied.

Chapter 3 – Research methodology

This chapter outlines how the data was collected, processed and analysed for the purposes of answering the research question. To answer the research question a particular research methodology should be followed in order to address the objectives of the study. The Define, Measure, Analyse, Improve and Control (DMAIC) steps are a proven roadmap for any process improvement project (Rever, 2016). The (DMAIC) research methodology was used in the study. The problem at the Foundry was identified and data was collected and analysed and recommendations were suggested.

Chapter 4 – Phase 2: Measure - Current State Analysis

This chapter describes the Foundry process in detail and the root cause analysis of why there are quality issues occurring and how they occur. This was achieved through observation of the operations. The standard operations that should be done during any process in the Foundry were stated versus the actual processes that are followed which deviate from the standard process and the resultant discrepancies were recorded. The discrepancies were then associated with the defects that occur as a result. The current state analysis gives a brief background of the Transnet Foundry to enable a fuller understanding of research findings.

Chapter 5 – Data Collection

Data was collected at the different sections in the Foundry. Data was collected from historical records from all the sections in the Foundry. In addition participant observations through involvement in production process and attendance of meetings were done. Direct observations were conducted on some of the processes where no archived data could be found. Informal interviews were done with supervisors who were asked questions about operations in their sections. The results obtained from this source indicated bias based on their attitudes towards the process.

Chapter 6 – Data Analysis

This chapter gives an in depth analysis of the data that was collected in the study. The analysis should address the cost of quality to productivity and there is quantification of the impact of defects on the profitability of the business .The research approach as defined in Define, Measure, Analyse and Improve (DMAIC) was used in this study. In the Foundry, all the processes a casting undergoes were analysed and the results interpreted in an effort to answer the research question. Analysis tools such as bar charts, pie charts, graphs and control charts have been used to illustrate the state of quality in the Foundry. The analysis was done to ensure conclusions established in the literature review correlates with the results.

Chapter 7 – Discussion

This chapter outlines the explanation of the results. The results are correlated with the literature for validation. The objectives are checked to assess if they have been answered sufficiently. The research question is also answered and explanations derived from all the variations are explained.

Chapter 8 – Conclusion

This chapter determines if the study conducted has been a success or a failure. In the conclusion all the objectives should be answered and all the consolidated research findings should be noted.

Chapter 9 – Recommendations

This chapter outlines the measures that should be taken to ensure that there is an improvement in the system that has been studied and it also outlines possibilities of further study.

Chapter 10- References

This chapter outlines all the sources that have been used in the study to acknowledge that extensive research on the subject matter has been conducted.

Chapter 11: Consent

This refers to the forms that were signed between Transnet and the author to show that permission was granted in order to conduct the study.

Chapter 12 – Appendices

This refers to all the data that was collected and could not be placed in the main body of the report.

2. LITERATURE REVIEW

2.1 The Foundry industry overview

The South African Foundry industry forms part of the manufacturing sector. The manufacturing sector contributes some 15% to the South African total GDP (Jennings, 2010). According to the South African Institute of Foundry-men (SAIF), South Africa casts almost 500 000 tons of metal a year, generates a revenue of R10.3 billion a year and also contributes 0.32% to the total country's GDP (SAIF, 2015). The Foundry industry operates 230 companies nationally and it employs over 15 000 workers (SAIF, 2015).

There are different types of steel casting processes and they include sand casting which is used for high volumes, chemically bonded sand which is used where smaller numbers are required, ceramic block moulds which is used when a good surface is required and low wax investment casting used for smaller castings made in large numbers where a good surface finish and dimensional accuracy is needed (Brown, 2000). Sand casting is the most popular casting process with low cost and high efficiencies and reuse (Mpanza, Nyembwe, & Nel, 2013). The challenges experienced when using the sand casting method is one of a high scrap rate in completed casted products (Mpanza, Nyembwe, & Nel, 2013) (Danko & Holtzer, 2006). Castings are produced from patterns and a pattern can be defined as a replica of the product to be cast, used to prepare the sand cavity into which molten metal will be poured during the casting process (Beeley, 2001). Pattern making is a high level skill that can be performed by a person with excellent drawing skills (Mpanza, Nyembwe, & Nel, 2013).

2.2 Metal casting industry process

A typical Foundry includes melting, metal treatment, preparation of moulds and cores, casting of molten metal, cooling solidification, removing the casting from the mould and finishing of the raw casting in the finishing shop. The casting process is described below (Alena, Marianna, & Dana, 2010).

- A mould is created into which molten metal will be used and it often consists of a bottom and top mould. The mould can be classified into lost moulds (single use mould) and permanent mould (multi –use).

- The mould can be filled with molten metal by gravity or by injection at low pressure or high pressure (die cast). A pouring furnace is usually used.
- After pouring, a casting is cooled to allow for solidification and it is then removed from the mould for further cooling.
- In sand processes a shakeout process is done to remove all the sand

Afterwards different processes may be required such as the removal of the running and gating system, removal of residual moulding sand from the surface and core remains casting activities, removal of pouring burrs, and repair of casting errors and mechanical preparation of the casting for post treatment (Alena, Marianna, & Dana, 2010). The process flow for the typical casting process can be seen in Figure 2-1. The pictorial process flow can be seen in Figure 2-2.

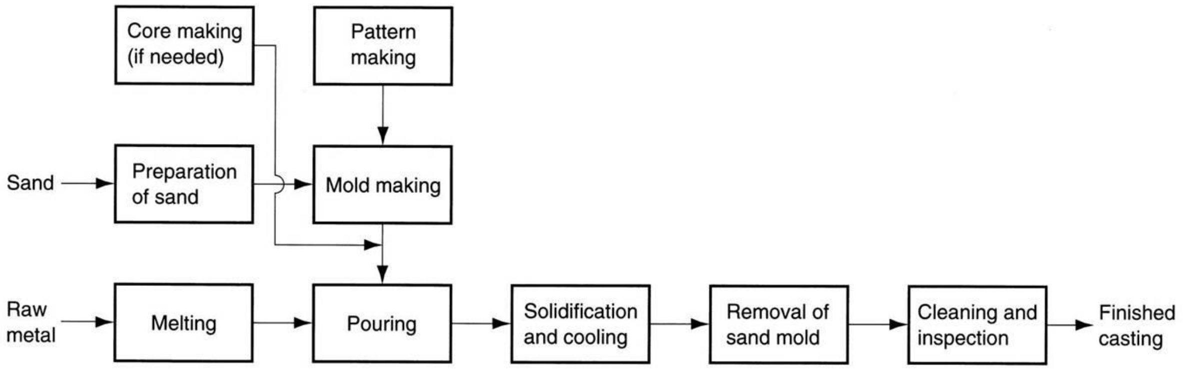


Figure 2-1: Sand casting process flow (DHF, 2015)

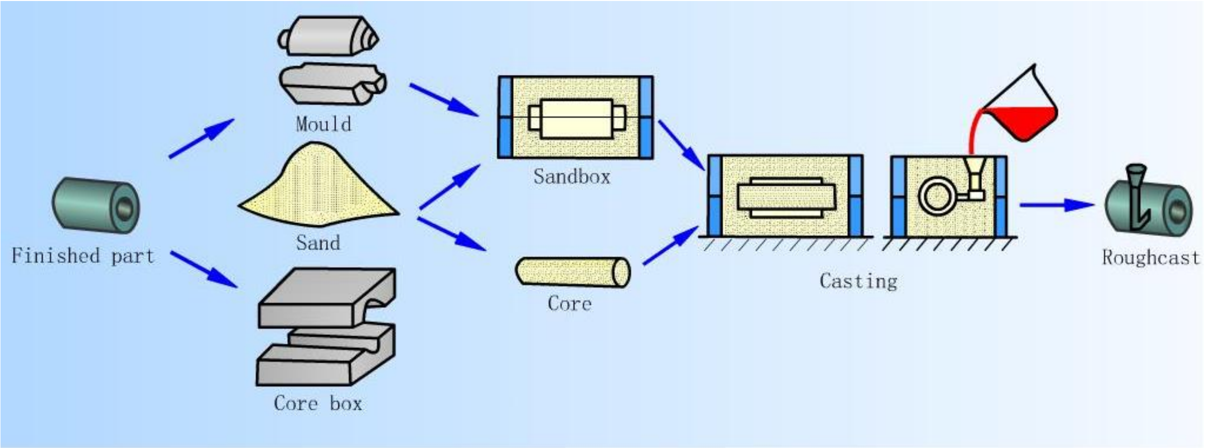


Figure 2-2: Sand casting process (DHF, 2015)

2.2.1 Green Sand Preparation

Green sand is made of wet sand that is used for moulding and the name comes from the fact that wet sands are used in the moulding process (Brown, 2000). Green sand is not green in colour but wet in the sense that it is used in a wet state. It comprises silica, chromite or zircon sand (75-85%), bentonite clay (5-11%), water (2-4%), inert sludge (3-5%) and anthracite (0-1%) (Land, Voigt, Cannon, Goudzwaard, & Luebben, 2002).Transnet Foundry uses silica sand. Using green sand has numerous advantages which include affordability and availability. Green sand can be recycled and the manufacturing cycle is short and the working efficiency is high. The Foundry reclaims sand. Sand reclamation is the process of cleaning previously used sand, that it can be reused. The tests that should be done daily at the Foundry are specified by the Foseco handbook and they include compactability, moisture, specimen weight, permeability, green compression test, dry compression strength, methylene blue clay content, total clay and active clay, Loss Of Ignition(LOI), volatile and green shear (Brown, 2000)

2.2.2 Chemically bonded sand preparation

To achieve chemically bonded sand, a binder, sand and a hardening chemical are mixed together to ensure that the binder and hardener react. The reaction that occurs is sufficiently slow to allow the sand to be formed into a mould or core which continues to harden further until strong enough to allow a casting (Brown, 2000). The standard tests that should be conducted for chemically bonded sand include Sieve, Mesh, % Retained Factor, Product, %Fines, Bulk density and pH (Brown, 2000). Transnet Foundry does not conduct these tests.

2.3 Casting Defects

2.3.1 Analysis of casting defects

Quality can be perceived in accordance with requirements and customer needs (Ott, 1997). Casting defects can negatively impact the bottom line of the Foundry (Ott, 1997). At their simplest level, they manifest as rework costs or casting scrap costs (Ott, 1997). The Foundry personnel may not have the time to conduct a detailed casting defect analysis, determine root causes and implement corrective and effective action stop prevent re/occurrence of these defects (Alena, Marianna, & Dana, 2010).

Several types of defects may occur during casting, considerably reducing the total output of castings besides increasing the cost of their production. It is therefore essential to understand the causes behind these defects that create a deficiency or imperfection contrary to the quality specifications imposed by the design and the service requirements. Defects in castings may be of three basic types as described below (Alena, Marianna, & Dana, 2010)

- Major defects, which cannot be rectified, resulting in rejection of the casting and total loss;
- Defects that can be remedied but whose cost of repair may not justify the salvage attempt;
- Minor defects, which clearly allow the castings to be economically salvaged and thereby leave a reasonable margin for profit.

Broadly, the defects may be attributed to the factors described below (Alena, Marianna, & Dana, 2010):

- Unsuitable or unsatisfactory raw materials used in moulding, core making or casting;
- The application of unsatisfactory moulding or casting practice by the individual worker or incorrect advice by the supervisor;
- The use of improper tools, equipment, appliances, or patterns, and unprofessional management policy, physical aspects such as temperature, speed, cooling and set time, faulty organisation and poor work discipline, or lack of training.

The common causes of green sand casting defects are as a result of expansion, metal penetration, gas and weak sand (Kay & Nagel, 2001). Silica sand expands the most when in contact with molten metal and beyond expansion some defects are moisture related. When Foundries are faced with these challenges the following remedies should be applied to the sand system and they include (Kay & Nagel, 2001):

- Adding cellulose to the sand to provide a place for expansion to occur.
- Lowering the moisture content of the moulding sand which increases the overall mould strength.
- Lowering the pouring temperature of the metal (eliminate excess super heat) which reduces sand expansion.
- Lowering the temperature of the moulding sand from the return sand system to increase the strength properties of the sand.
- Increasing the clay content of the sand especially bentonite for better hot strength properties.

- Decreasing the amount of fines in the sand. Fines tend to soak up water, increasing overall mould moisture without increasing mould strength.
- Avoiding over-ramming or over squeezing the mould as this pushes moisture closer to the mould surface thereby increasing the probability for defects.

In chemically bonded sand, the use of water-based coatings on moulds made with chemically bonded sand, can affect the strength of the bond (Brown, 2000).

The fish bone diagram shown in Figure 2-3 makes a possible identification of sources of problem, formations, which help quality personnel identify the sequence of causes of non-conformance through research and assists diagnosis (Alena, Marianna, & Dana, 2010).

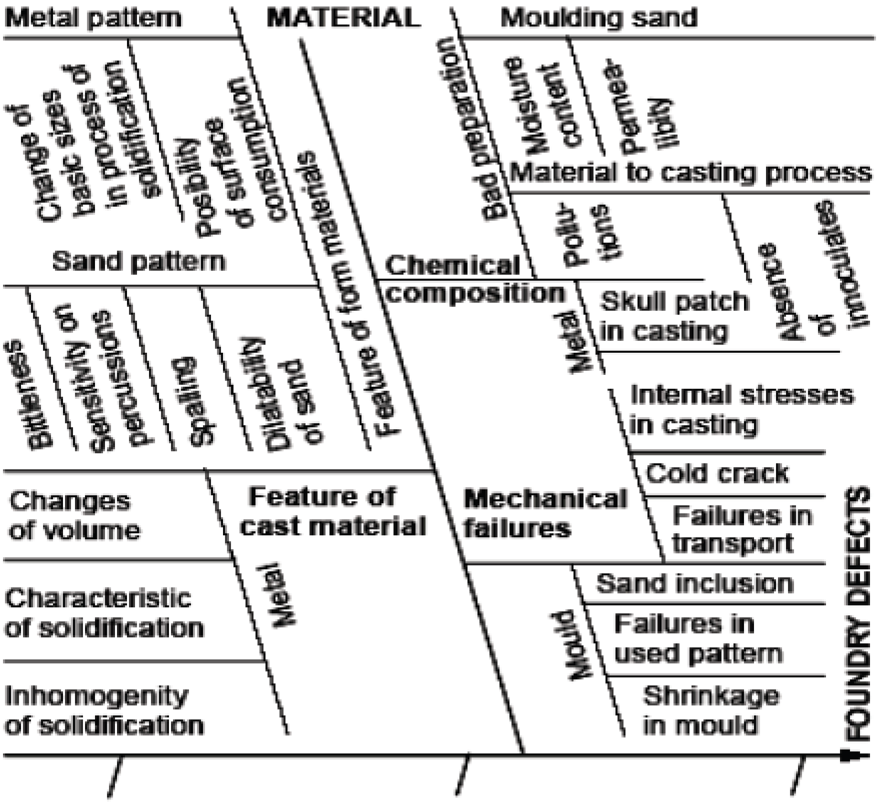


Figure 2-3: Casting defects (Alena, Marianna, & Dana, 2010)

Casting defects can be classified as a filling related defect, shape related defect, thermal related defects and defect by appearance (Rajkolhe & Khan, 2014). Filling related defects include blowhole, sand burning, sand inclusion, cold shut, misrun and porosity. Shape defects include mismatch defect, distortion or warp and flash defect (Rajkolhe & Khan, 2014). Thermal defects include cracks or tears, shrinkage and sink mark. Defects by appearance include metallic projection, cavities and discontinuities (Rajkolhe & Khan, 2014)

2.3.2 The most common defects

There are many variables in the production of metal casting and all the data that is related to the production of casting defect is identified in an attempt to eliminate the defect by taking appropriate corrective action (Chaudhari & Thakkar, 2014). Any irregularity in the moulding process causes defects in castings which may not be tolerated at some point. The following are the major casting defects (Chaudhari & Thakkar, 2014):

- Gas defect - These can be classified into blow holes and open blows, air inclusion and pin hole porosity. These defects appear in all regions of the casting. These defects are caused by the lower gas passing tendency of mould and improper design of the casting.
- Shrinkage activities - This defect occurs as a result of solidification of the casting. This is caused by the volumetric contraction in liquid and solid state and low strength at high temperature.
- Moulding material defects - These defects are caused as a result of the characteristics of moulding and they are caused by the erosion of the moulding sand by the flowing molten metal. In some instances, it may result because the moulding sand does not have enough strength, higher pouring temperatures and the faulty mould making procedure.
- Pouring metal defect - These defects include misrun, cold shuts and slug inclusions. These are the result of either the metal being unable to fill the mould cavity completely or they may be caused by premature interruption of pouring due to workman’s error.
- Metallurgical defect - This defect may include hot ears and hot spots. These are mainly caused by poor casting design, damage to the casting while hot, rough handling, and excessive temperature at shakeout or the chilling of the casting.

It is imperative to avoid high velocity impingement in of the metal stream onto the cores and mould surfaces and this can be achieved by using running and gating systems (Ott, 1997). The running and gating systems also encourages thermal gradients within the casting, which help to produce sound castings (Alena, Marianna, & Dana, 2010). It is imperative to control the flow of metal into the mould cavity at the rate needed, to avoid cold metal defects in the casting (Ott, 1997).

2.3.3 Heat treatment of ductile iron

It is obviously desirable to achieve the required properties in the as-cast form, but this is not always possible because of variations of section thickness (Brown, 2000). Heat treatment of the castings will eliminate carbides in thin sections and produce more consistent matrix structures for a given structure. The mechanical properties are often improved by heat treatment, especially by normalising. Where tempered martensite structures are needed, heat treatment is essential (Brown, 2000).

2.4 Quality management in Foundries

Due to tough economic conditions and competition, foundries have developed the need to produce high quality products through manufacturing process excellence (Devadasan, Muthu, Samson, & Sankaran, 2003). This reduces rejections due to failures in the parts being cast (Devadasan, Muthu, Samson, & Sankaran, 2003). In order to maintain a market position, foundries have to adapt to constantly increasing demands whilst simultaneously improving the quality and functioning of their products (Hahn, 1999). This need to improve the quality of the product being cast, prompted the implementation of globally accepted approaches like Total Quality Management (Chapman, Bernon, & Hagett, 2011), Statistical Process Control (Sika & Ignaszak, 2009), Six Sigma (Kumar, Satsangi, & Prajapati, 2011), Foundry Total Failure Mode and Effect Analysis (Krishnaraj, Mohanasundram, & Navaneethasanthakumar, 2012), Qualifound (Santos & Barbosa, 2006).

2.4.1 Statistical Process Control in Foundries

Statistical process control (SPC) is a statistical method which is used for evaluation and supervision of the production stability and is often represented in the form of an average value, range or standard deviation of an examined parameter which is measurable and clearly indicates fulfilment of a certain criterion by the product (Ignaszak & Sika, 2012). The application of SPC has been stimulated by the increasing requirements of the Foundry customers and they want adjustment to the production standards in the field of design/development, production, installation and maintenance of the products for the automotive branch (Ignaszak & Sika, 2012).

The Foundry is a very complex type of a manufacturing system where there is a high degree of variability of manufacturing processes (Sika & Ignaszak, 2009). These processes include the production of moulding sand, moulds, cores and the melting of an alloy of appropriate chemical composition. These are preceded by the preparation of input materials like moulding materials, scrap and alloy addition. The process data can be collected in a classical form such as paper records or electronically in the form of databases (Sika & Ignaszak, 2009).

In Foundry engineering, SPC is used for evaluation of the process stability (its measurable stages). The specification limits of parameters required by the customer or assumed by a process engineer deal with the final quality of the product which is a set of at least several complimentary parameters (Sika & Ignaszak, 2009).

2.4.1.1 Process Capability

Process capability is the ability of a process to meet design specifications which are set by engineering design or customer requirements (Heizer & Render, 2014). Even though the process may be statistically in control, the output of that process may not conform to specifications (Heizer & Render, 2014)**.** The formula for calculating process capability can be seen in the calculation below:

$$\mathrm{C_p}\ (\text{Process Capability}) = \frac{\text{Upper Specification Limit (USL)} - \text{Lower Specification Limit(LSL)}}{6\sigma}$$

2.4.2 Six sigma an excellent tool for process improvement

Many foundries are interested in implementing six sigma to improve the quality of their products (Arita & McCann, 2002). Implementation of six sigma methodology in the Foundry has become popular (Kumar, Satsangi, & Prajapati, 2011).

Taguchi’s methods have been used to optimise the mechanical properties of the vacuum casting process (Barua, Kumar, & Gaindhar, 1997). Their prime focus is on minimising the casting defects developed in components manufactured in the green sand casting process (Kumar, Satsangi, & Prajapati, 2011). The casting process has a large number of parameters that may affect the quality of the casting. Some of these factors are controllable whilst others are noise factors (Antony & Banuelas, 2002).

Quality can be improved by adopting a six sigma approach especially through the Define Measure Analyse Improve Control (DMAIC) approach of the parameters at the lowest possible cost (Kumar, Satsangi, & Prajapati, 2011). It is also possible to identify the optimum levels of signal factors at which the noise factor effect on the response parameters is less and to optimise process parameters of the green sand casting process. This contributes to minimising the casting defects. The phase of Six Sigma DMAIC Methodology can be seen in Table 2-1.

Table 2-1: Six Sigma DMAIC Methodology (Abidakun, Leramo, Ohunakin, Babarinde, & Ekundayo-Osunkoya, 2014)

Phase	**Items**	**Tools**
Phase 1: Define	Who are the customers are? What do customers require? The critical aspects to Quality. Analysis of the ability to improve the process.	Voice of the Customer Voice of the process Supplier Input Process Customer (SIPOC)
Phase 2: Measurement	Determine the sigma levels of the process. Identify inputs. Non-Conforming products. Defect type and probable cause.	Statistical Process Control (SPC)
Phase 3: Analysis	Exploratory analysis. Identify potential critical input. Description analysis. Analysis of the ability to improve the process.	Process capability analysis Descriptive statistical analysis Run Charts Regression analysis Ishikawa (Fishbone Diagram)
Phase 4: Improvement	Analysis of improve of the process.	
Phase 5	Implement control plan. Verify long term capability. Continuously improve process.	

2.5 Quality Management

Quality management aims at conducting inherent managerial elements of planning, control and improvement (Juran, 1992). Quality control as is it is known today did not exist in the eighteenth and nineteenth centuries although some quality control activities were performed informally by individuals at workshop level (Garvin, Quality on the line, 1983). The development and evolution of the function of quality control started during and spanned the entire twentieth century (Feigenbaum, 1983). JC Penny in 1913 was one of the earliest to present the fundamentals of a Total quality management philosophy, when he suggested concepts such as customer satisfaction, fairness, quality, value, associate training and rewards for performance to be a managerial basis for business (Jablonski, 1994). Frederick W. Taylor also presented quality concepts in the early 1900s. He was known as the father of scientific management (Garvin, Managing Quality: The Strategic and Competitive Edge, 1988). Evolution of quality management can be seen in Figure 2-4.

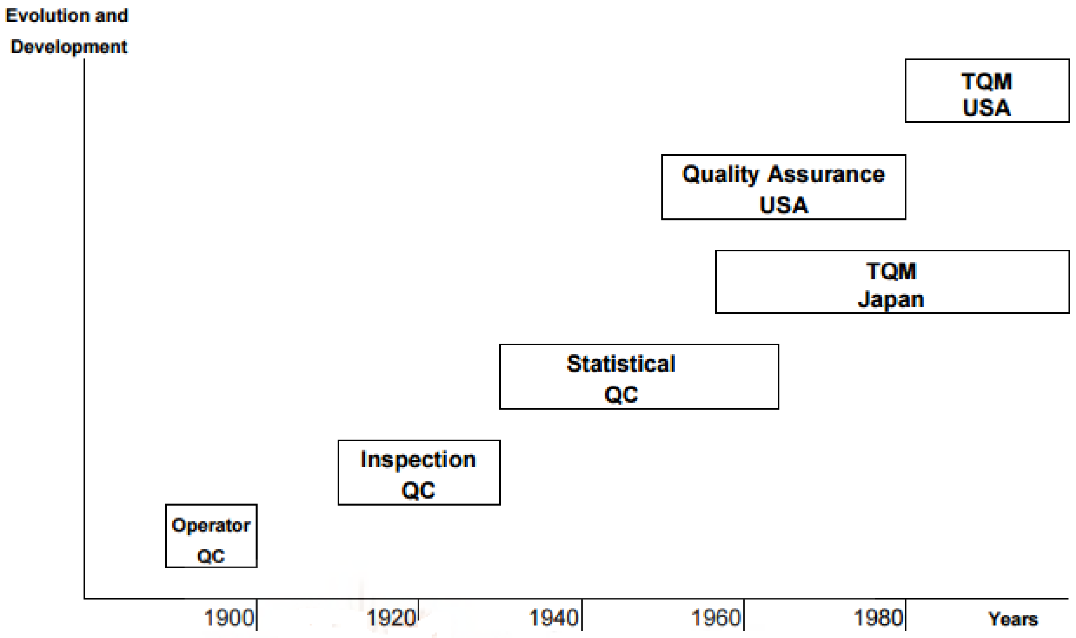


Figure 2-4: Evolution of quality management (Feigenbaum, 1983)

2.5.1 Define Measure Analyse Improve Control (DMAIC) Six Sigma

Increasing customer requirements and production costs forces casting manufacturers to adopt a methodological approach to manufacturing processes (Furgal & Cygan, 2009). This is done in order to deliver increasingly more repeatable, predictable and competitive products (Furgal & Cygan, 2009). One of the methods of achieving such results is the reduction of variability of manufacturing processes and the optimization of their control. The aim of DMAIC methodology is the satisfaction of customer requirements and the support of business development through the elimination of defects and variability reduction, based on facts and data, and using proper statistical tools (Furgal & Cygan, 2009).

Variation in the process is denoted by sigma which is the standard deviation of measurements around the process (Gryna, Chua, & DeFeo, 2007). Six sigma uses five phases which include Define, Measure, Analyse, Improve and Control. This can be shown in

Figure 2-5. The six sigma approach has an objective of finding the cause of deficiencies and developing remedies to prevent future deficiencies (Gryna, Chua, & DeFeo, 2007).

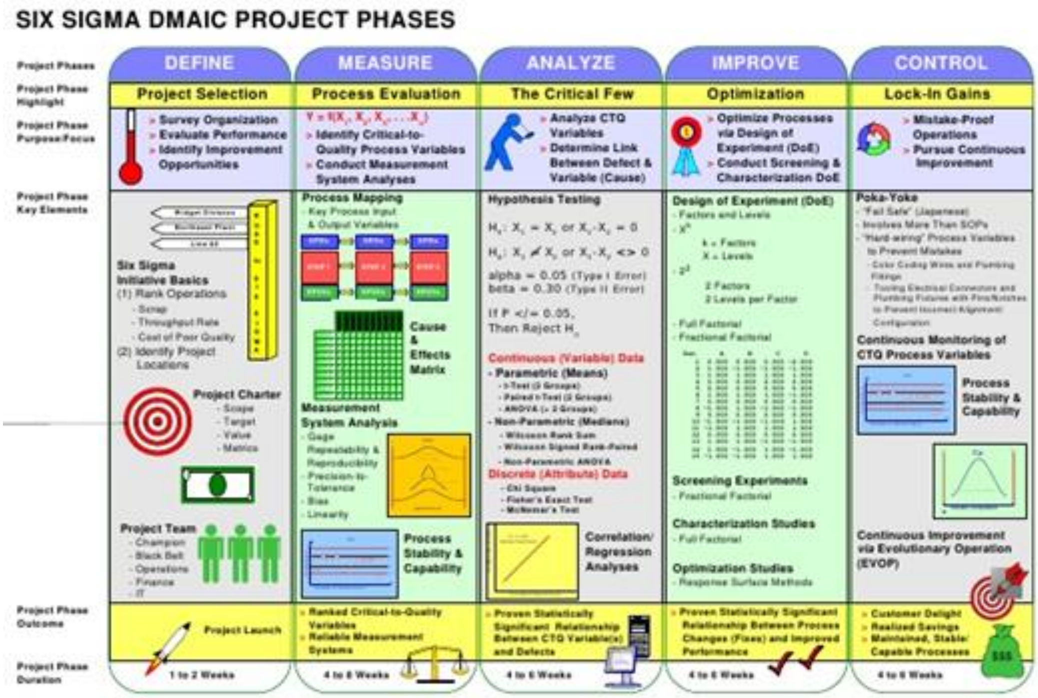


Figure 2-5: Six Sigma DMAIC Project Phases (Gryna, Chua, & DeFeo, 2007)

The DMAIC process

The three phases of the DMAIC process will be discussed below and they include the Define, Measure and Analyse phase.

Phase 1: Define the Problem

This phase according to (Gryna,Chua, & DeFeo, 2007) consists of:

- Identifying potential projects - The focus must be on the vital few opportunities that will increase customer satisfaction and reduce poor quality. The Pareto principle is a data analysis tool for generating project nominations.
- Evaluating the project - Project nominations are usually reviewed by middle management and recommendations are then made to upper management for final approval. Pareto analysis is an example of data mining which is a process for analysing data to extract information that is not offered by raw data alone. The Pareto principle identifies the vital few projects for improvement and these projects are the major contributors to quality leadership in terms of sales revenue and lower costs.

- Selecting the project - the successful project is a form of evidence for the project team members that informs improvement process to useful results should the project should deal with a chronic problem, the feasibility of the project should be significant and the results should be measureable in terms of money as well as technological terms.
- Preparing problem and mission statements or the project - A mission statement is based on the problem statement but provides direction for the project team. A goal or other measure of project completion and a target date should be defined. A mission statement should not imply cause or solution.
- Selecting and launching project team - To help launch a team, some organisations develop a charter that defines what the team will do and how the team will function.

Phase 2: Measure – Current state mapping

This phase identifies key product parameters and process characteristics and measures the current process capability and the steps as defined Gryna, Chua & Deo (2007). See below:

- Verify the project need - this process serves two purposes which are to ensure the time to be spent by the project team is justified and to help overcome resistance to accepting and implementing a remedy.
- Document the process - This step records the information and activities under study relating to actual or potential problems and it is a useful tool.
- Plan for data collection - Chronic problems are not easy to solve and require careful planning and collection of data to confirm and analyse the input and output variables. Planning for data collection involves matters such as where does data accuracy occur, separation of data into categories and whether the data is sufficient in content and quantity for the data analysis tools.
- Validate the measurement system - The variation in observed measurements from a process is from the variation of the process itself and variation of the measurement system. Measurement capability involves both the ability of people making measurements and the capability of measuring instruments. When necessary a complete measurement capability study can involve matters such as reproducibility, repeatability, accuracy, stability and linearity.
- Measure the process capability - Process capability refers to the inherent ability of a process to meet the specification limits of a product. In the measure phase, the initial process capability is established by obtaining measurements and observing how the process variability compares with the specification limits.

Phase 3: Analyse

This phase analyses past and current performance data in order to identify the causes of variation and process performance. The steps as described by Gryna, Chua & Deo (2007) are given below:

- Plan for data collection - The key questions are how do we generate useful information and how does the researcher formulate the question in a way that generates the information required?
- Collect and analyse data - To deal with deep seated beliefs, it can be useful to conduct studies to separate defects into broad categories of responsibility. Broad studies provide important direction for improvement but individual projects require their own unique data collection and analysis.
- Test theories (hypothesis) on source of variation and cause and effect relationship - Some problems become chronic because the true causes have not been determined even though a flurry of action takes place. The factual approach not only determines the true cause, but also helps to gain agreement on the true cause by all involved parties. Creating a flow diagram helps understand the progression of steps in a process.

Phase 4: Improve

In the DMAIC Improve phase, the project team seeks to quantify the cause–effect relationship (mathematical relationship between input variables and the response variable of interest) so that process performance can be predicted, improved, and optimized (Gryna, Chua, & DeFeo, 2007). The team may utilize designed experiments (DOE) if applicable to the particular project (Gryna, Chua, & DeFeo, 2007). Screening experiments are used to identify the critical or “vital few” causes or determinants. The deliverables for “improve” have been listed below (Gryna, Chua, & DeFeo, 2007):

- Plan for designed experiments.
- Reduced list of vital few inputs (Xs).
- Mathematical prediction model(s).
- Established process parameter settings.
- Designed improvements.
- Implementation plan.
- Plans to deal with cultural resistance.

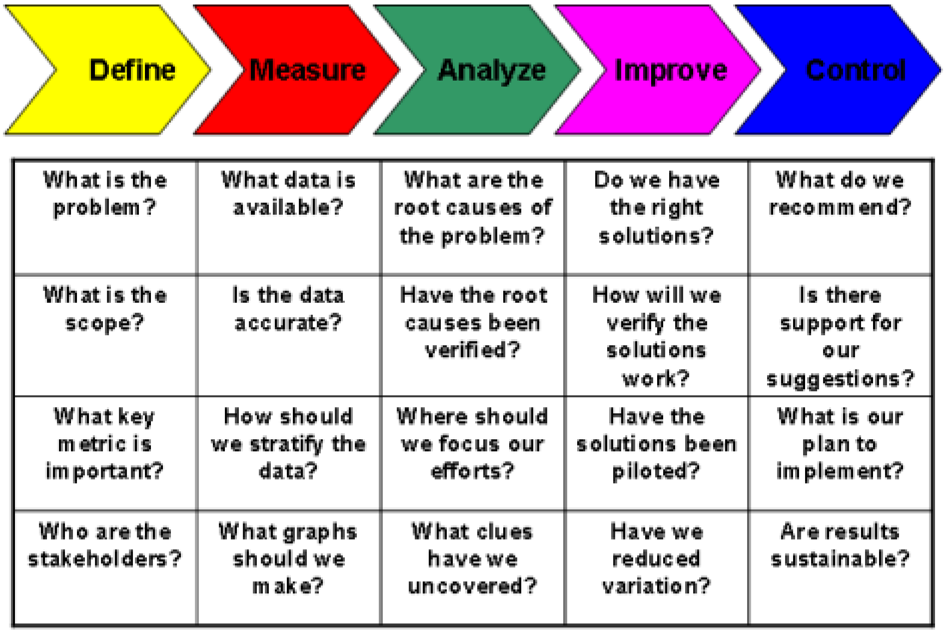
Phase 5: Control

The DMAIC project team designs and documents the necessary controls to ensure that gains from the improvement effort can be sustained once the changes are implemented (Gryna, Chua, & DeFeo, 2007). Sound quality principles and techniques are used, including the concepts of self-control and dominance, the feedback loop, mistake-proofing, and statistical process control (Gryna, Chua, & DeFeo, 2007). Process documentations are updated (e.g., the failure mode and effects analysis), and process control plans are developed (Gryna, Chua, & DeFeo, 2007).

Standard operating procedures (SOP) and work instructions are revised accordingly. The measurement system is validated and the improved process capability is established (Gryna, Chua, & DeFeo, 2007). Implementation is monitored, and process performance is audited over a period of time to ensure that the gains are held (Gryna, Chua, & DeFeo, 2007). The project team reports goals accomplished to management, and upon approval, turn the process totally to the operating forces and disband (Gryna, Chua, & DeFeo, 2007). The deliverables for “improve” have been listed below (Gryna, Chua, & DeFeo, 2007):

- Updated Failure Mode Effect Analysis (FMEA) process control plans, and standard operating procedures.
- Validated capable measurement system(s).
- Production process in statistical control and capability to get as close to Six Sigma levels as is optimally achievable, at minimum to accomplish the project goal.
- Updated project documentation, final project reports, and periodic audits to monitor success and hold the gains

In conclusion, the DMAIC steps are a proven roadmap for any process improvement project. There are only five steps so they are relatively easy to remember and they offer a structured approach to solving problems and improving results (Rever, 2016). There are certain questions to be addressed under each step and certain tools and techniques can be utilized to answer those questions through facts and data (Rever, 2016).



Define	Measure	Analyze	Improve	Control
What is the problem?	What data is available?	What are the root causes of the problem?	Do we have the right solutions?	What do we recommend?
What is the scope?	Is the data accurate?	Have the root causes been verified?	How will we verify the solutions work?	Is there support for our suggestions?
What key metric is important?	How should we stratify the data?	Where should we focus our efforts?	Have the solutions been piloted?	What is our plan to implement?
Who are the stakeholders?	What graphs should we make?	What clues have we uncovered?	Have we reduced variation?	Are results sustainable?

Figure 2-6: Summary of DMAIC (Rever, 2016)

DMAIC Six Sigma helps to avoid the majority of errors committed during the realization of projects such as lack of a precise, data-based, definition of the problem, lack of a precisely defined project scope, lack of analysis of the customer feedback ,lack of measurement system verification or not entirely thought through, not facts based technological trials (Furgal & Cygan, 2009). In the organization area, Six Sigma is a chance to improve the quality of teamwork, communication, and employee competence, knowledge about product and processes, customer satisfaction (Furgal & Cygan, 2009).

2.5.2 Tools and Techniques

The six sigma analyse phase is the third of the five stages of a DMAIC project. This is where a number of statistical analyses are used to identify the variables which consistently control the process (Process, 2016). Every project is different of course, but tools typically used during the DMAIC analysis phase include linear regression, design of experiments and Pareto analysis (Process, 2016).

a) Process Maps – Process Map/Process Mapping is a graphical representation of all the activities carried out to deliver output for a process. It records all the activities being carried out to obtain the output (Institute, 2016). It also discusses the inputs going to deliver the output. It suggests which inputs are controllable and which are not (Institute, 2016). It gives a list of critical inputs. It shares which of these activities are value added and which are non-value added, including the various handoffs and opportunities to eliminate steps (Institute, 2016). It helps to determine the bottlenecks and provides existing data collection points alongside those required (Institute, 2016). It also helps in identifying the efficiency of the process as it captures the processing time for each activity (Institute, 2016). There are several different approaches to process mapping and the key is to determine who does what at each step of the process. The simple drawing of a process map is sufficient to solve many quality problems because the map shows where defects can arise (Melsa J. , 2006). Flow charting helps in illustrating processes and there are many quality related processes that will be analysed in the research. The process flow chart is used in the measure phase where defects are defined, opportunities for defects occurring are identified and the respective units and metrics are listed (Jafari, 2010).

b) Statistical tools – One of Deming's major contributions to the quality movement was the introduction of the statistically grounded approaches to the analysis of defects. Without the use of tools, one can often make incorrect decisions regarding the cause of a problem. This can often lead to consequences the opposite of those being sought. Included in this set of tools are statistical process control (SPC) charts, Pareto charts and histograms. Histogram is the most commonly used graph for showing frequency distributions, or how often each different value in a set of data occurs and this will be useful when analysing defects in the Foundry (Jafari, 2010). The Pareto chart shows on a bar graph which factors are more significant and this tool will be applicable in the study (Jafari, 2010). Pareto charts are bar charts in which the horizontal axis is split into categories such as defects (Process, 2016). The chart then shows the frequency of each defect occurring in descending order of magnitude. Often a line graph is superimposed to show the cumulative frequency (Process, 2016). The benefit of using a Pareto chart is that it clearly displays where to focus improvement efforts by separating the few problems of high importance from the many problems with low importance (Process, 2016).

c) Fish Bone Diagram (Ishikawa diagram) – This tool is also called the cause and effect diagram and it is used in the brainstorming session to examine factors that may influence a given situation or outcome (Melsa J. , 2005). The causes are often grouped into categories such as people, material, method or process and equipment (Melsa J. , 2006). The fish bone diagram helps in identifying the possible causes for a problem which then get sorted into their specific categories. The line along the centre represents the problem with all the possible causes branching off it (Process, 2016). The advantage of using this tool is that causes are arranged in level of importance (Process, 2016).

2.6 Foundry Quality Issues

There are a variety of problems related to product quality and productivity in industries due to varying degrees of abnormality and inefficiency which ultimately causes rejection (Mahto & Kumar, 2008) . The production of metal castings is a very complex process. There are many processes involved, such as gating design, raw material control, melting, pouring, sand control, moulding, cleaning, grinding, machining and any mistakes or unstable factors will cause some problems and defects (Mahto & Kumar, 2008).

Many researchers reported that 90% of the defects in castings are due to the wrong design of gating and risering system and only 10% due to manufacturing (Iqbal, Patel, & Vidyarthee, 2014). In South Africa, in 2007 alone, twenty foundries were closed down when the casting industries directory was released (Mpanza, Nyembwe, & Nel, 2013). High scrap rate due to lack of quality management was one of the root causes of low productivity and low profits (Mpanza, Nyembwe, & Nel, 2013). Quality issues arise as a result of poor design of patterns or inadequate pattern equipment (Plaines, 1974). Casting defects are those characteristics that create deficiency or imperfection to quality specifications imposed by design and service requirements (Avallone, Baumeister, & Sadegh, 2007).

It is unavoidable that many different defects occur in casting process such as porosity and incomplete filling and how to improve the casting quality becomes important (Liu, 2008). Increasing customer requirements and production costs has forced casting manufacturers to adopt a methodological approach to manufacturing processes (Furgal & Cygan, 2009). The application of the DMAIC methodology with its statistical tools allows an efficient identification of quality issues and reduction of process parameters basing on data, number and facts (Furgal & Cygan, 2009). It gives measurable financial profits in reducing the costs of poor quality and a number of non-financial benefits such as developing team work skills and deepening the process knowledge together with the knowledge of root problem causes (Furgal & Cygan, 2009).

2.7 Cost of quality

Quality costs are a tool that displays trends for management to act upon (Zimwara, Mugwagwa, Maringa, Mnkandla, Mugwagwa, & Ngwarati, 2013). It is important to carry out quality cost analysis in an organization so that this information can be used by management to identify quality costs, prioritize quality cost reduction activities and measure the success of such activities (Zimwara, Mugwagwa, Maringa, Mnkandla, Mugwagwa, & Ngwarati, 2013). Results from previous research revealed that quality costs were 10-30 per cent of sales or 25 to 40 per cent of operating costs. These were the result of poor quality products (Rodchua, 2006). The application of the cost of quality approach in the Foundry industry environment provides a systematic, structured approach to the quality problem and identification of correction that focus on unfavourable variances in operational performances (Zimwara, Mugwagwa, Maringa, Mnkandla, Mugwagwa, & Ngwarati, 2013). The components of cost of quality include preventions costs, appraisal costs, internal failure costs and external failure costs (Gryna, Chua, & DeFeo, 2007).

2.8 Qualifound Framework

Qualifound enables the association of defects with the relevant process operations and identifies their possible causes (Santos & Barbosa, 2006). It also suggests the implementation of actions to eliminate or reduce their occurrence and this is the qualitative analysis mode of the system. The quantitative analysis mode deals with the number of castings produced and rejected and the calculation of the non-quality costs (Santos & Barbosa, 2006). The graphical interface of the qualitative analysis mode is composed of 12 protocols that make the correspondence between processes and defects and the graphical interface of the quantitative analysis mode is composed of 13 protocols namely parts report, the parts defect report, the where and how report, the defects casting and the correspondence of defects to orders (Santos & Barbosa, 2006). These protocols and report allow the analysis of the production per casting or selection of castings or per order, month or year. It is also possible to perform a Pareto analysis showing percentages of the most frequent production defects per casting (Santos & Barbosa, 2006). The validation of Qualifound was carried out in a Portuguese foundry, whose quality system had been certified according to the ISO 9000 standards. (Santos & Barbosa, 2006) Qualifound was used in every management area and it was concluded that the application had the required technological requisites to provide the necessary information for the foundry management to improve process quality (Santos & Barbosa, 2006).

2.9 Principle of statistical justification

A normality statement should be justified by statistical knowledge and not accepted against better statistical knowledge (Konstanz, 2010). The logic of statistical justification critics state that the statistical information is not sufficient for accepting a normality statement (Konstanz, 2010). Inferential statistics that psychologists use such t-test, ANOVA, simple regression rely on the assumption of normality (Mordkoff, 2011). In other words, these statistical procedures are based on the assumption that the value of interest (which is calculated from the sample) will exhibit a bell-curve distribution function if loads of random samples are taken and the distribution of the calculated value (across samples) is plotted (Mordkoff, 2011).

SigmaXL is the software that was used to do statistical justification. SigmaXL is a powerful but easy to use Excel Add-In that will enable you to measure, analyse, improve and control your service (SigmaXL, 2015). SigmaXL will helps in problem solving and process improvement efforts by enabling one to easily slice and dice data thus quickly separating the “vital few” factors from the “trivial many” (SigmaXL, 2015). SigmaXL utilizes the “Y=f(X)” model where Y denotes a key process output metric and X denotes a key process input metric (SigmaXL, 2015).

3. RESEARCH METHODOLODY

This chapter covers the methodology used in the research to achieve this outcome. The purpose of this chapter was to give a description of how and why data for this research was collected. Different tools used to gather data and methods of how the data was collected will be analysed.

The research approach used in the study is based on the DMAIC and is shown in Figure 3-1.

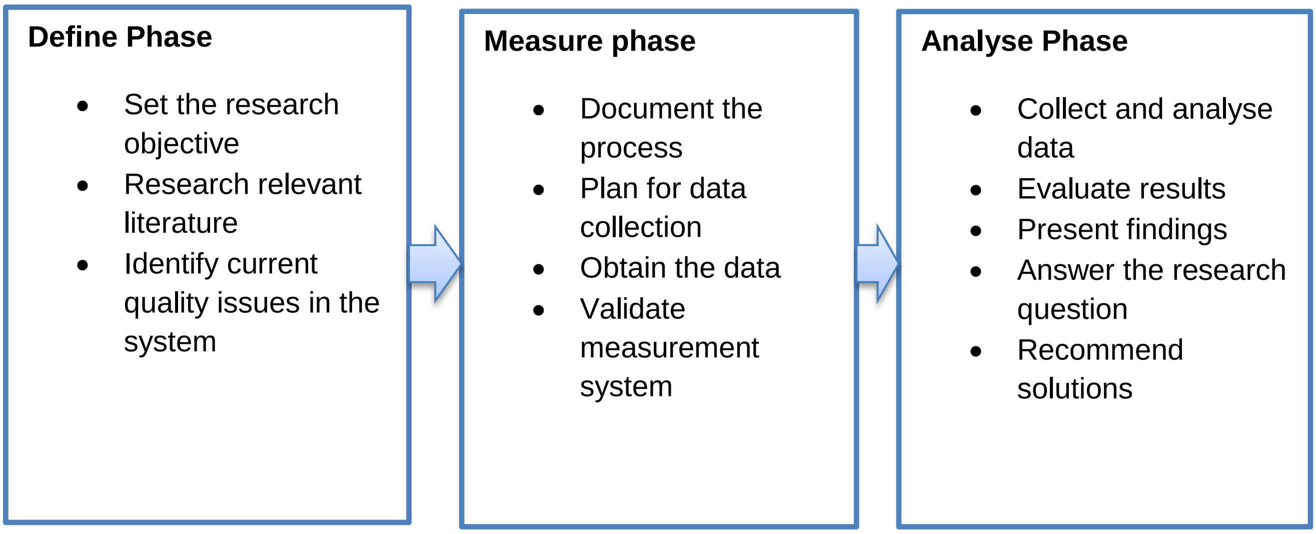


Figure 3-1: Research approach

3.1 Define Phase

The rationale for the selection of the project has been provided in Chapter 1. In summary this study will be conducted at Koedoespoort Transnet Foundry and it has been chosen because it does not adhere to continuous improvement systems. The site is experiencing high levels of scrap rate and defects. The Koedoespoort Foundry is also convenient place as it is geographically well placed for the researcher. Data will be collected for brake shoe holders and top centre castings as they generate more revenue for the Foundry business.

Thus the primary objective of the project is to investigate:

What improvements to the quality system of the Transnet Foundry will contribute to increased productivity, throughput and profitability.

This will be achieved by:

1. Investigating the quality issues in the Foundry.

The first phase of the study will involve observation of the production line in the Foundry. The observations will be done to identify the quality issues that are affecting efficiency in business. Process mapping will be done and cause and effect diagrams will be used to illustrate and to indicate the impact of quality problems. This will be done by observing the stages of the casting process which includes sand preparation, moulding making, metal pouring, casting, shake out, dressing and inspection of the final product (completed castings ready for shipment). Existing Foundry records from the quality department will also be analysed for further identification of quality issues which may be neglected or have not been observed in the process.

In the sand preparation process, green sand (new and reclaimed), water and chemical additives are added together. The sand laboratory tests the sand to check for moisture content, permeability and compactability against a specification. In the study, data records will be checked especially for instances when the sand was in and out of specification. This data will be collected to check the quality of the sand used in moulding and to determine how many times sand can be re-used without affecting the quality of the moulds. This information will give an indication of how the Foundry uses re-claimed sand and how this consequently affects the quality of the moulds as reclaim sand can only be used for a certain period of time.

In the mould making process data will be collected for all the moulds that will be made on that day. Cracked or broken moulds will also be recorded. Currently this is not being measured and for the purposes of the study, a data sheet will be created and supervisors for the moulding sections will be required to record the information. This information will show that the Foundry uses a fire fighting approach when addressing quality issues. When moulds crack and break, they will be repaired and the machine settings of the sand mixer will be adjusted and no root cause analysis will be done.

In the melting process, the scrap metal is melted and a sample is taken to the Spectrometer laboratory and it is checked to see if it contains enough Ferro alloys. If the Ferro alloys are not enough, more of them will be added until the right molten mix is achieved. This data will be collected to check if the molten metal that is produced has the correct balance of the metals such as manganese, silicon and mild steel. These records will give an indication of whether the molten metal complies with the composition specification at all times. The data will be obtained on the records of the spectrometer laboratory and it will be analysed by using pie charts and histograms.

In the heat treatment process, the records of the Foundry will be checked to see if the oven reaches the maximum temperature required to normalise the castings. The graphs that are plotted by the temperature regulators in the heat treatment ovens will be analysed by using Pareto charts and pie charts. These graphs can be obtained from the quality department. This information will give an indication of whether the castings are strong enough not to crack or break.

In shake-out and cutting of risers and runners, data will be collected for the castings that will have defects, specially casting shrinkage or short cast. These records will give an indication of the number of castings with identifiable defects before the casting can have finishing touches added to it. There are currently no records for such information and a data sheet will be formulated to collect the information for the purposes of this research. The data will be analysed by using Pareto charts and histograms.

In dressing and final inspection, most of the defects are identified and the information is captured by the quality department. Information at this process will be collected to classify the defects according to their types and to enable calculation of the cost of quality. The information will be analysed by using root cause analysis and Pareto charts.

2. Determining the total cost of quality for the Foundry business.

As part of this study it is imperative that the total cost of quality of the Foundry business be analysed. The cost of quality system includes of cost of prevention, cost of appraisal, cost of internal failure and cost of external failure (J.Czuchry, Yasin, & S.Little, 1999). In this study, the cost will be determined by recording the number of castings produced, number of castings rejected and computing the rejection rate. The price of each casting will be multiplied by the number of rejected castings (Arasu & R.Gandhinathan, 2005). The data will be collected from the quality department and from the data sheets that will be designed for areas that have no readily available data for the study. Supervisors will be asked to enter the relevant information of rejected castings or moulds relative to the total castings produced. The data will be analysed by using Pareto charts, pie charts and fish bone diagrams.

3. Investigating the impact of the specific defects on the productivity of the Foundry business.

Specific defects such as the gas defects, shrinkage defects, moulding material defects, and pouring metal defects will be analysed especially their cost to the total cost of quality. This will be done by inspecting the castings at the rejection area. Castings will be grouped according to their defects and they will be recorded on the data sheet and costing will be calculated by using the number of castings produced, number rejected (due to specific defect) and the percentage of rejection according to defect type.

The cost of defects per month will be compared with the anticipated and actual monthly profit of the business. The defects will be analysed per product type. This means that castings such as top centre castings and brake shoe holders will be analysed separately. This data is being collected to understand the impact of the different types of defects on the profitability of the business. The data to be analysed will be collected from the quality department and analysis will be conducted using Pareto charts, bar graphs and pie charts. The first three stages of the DMAIC process will be followed to achieve the research outcome, that is, to answer the research question. The current state of the Foundry will be analysed and this will involve identifying the defects and quality issues that occur from the beginning to the end of the process. Methods such as Pareto charts, histograms, pie charts and root cause analysis will be used.

The study will involve spending time in the Foundry to further understand the processes and to be able to explain variations in the process. Participant theory of observation will be used. Participant observation is the process enabling researchers to learn about the activities of the people under study in the natural setting through observing and participating in those activities (DeWalt & DeWalt, 2010). Being involved as a participant, involves more than observation as it also involves natural conversations, interviews of various sorts, checklists, questionnaires, and unobtrusive methods (Bernard, 1999).

The study will be conducted for a period of four months and the observations will start from the sand preparation process to the final inspection process. More emphasis will be placed on the quality processes and how they are monitored from the beginning to the end of the process. All the defects that occur during each process will be recorded. Previous company data will be collected from SAP system records and monthly quality business reports. Tools such as the root cause analysis diagrams and Pareto charts and pie charts will be used for analysis.

3.2 Phase 2 Measure and Phase 3 Analyse

The following data collection and analysis tools and techniques will be used in the Measure and Analyse Phases of the (DMAIC).

3.2.1 Data Collection

There are six common types of evidence used in a qualitative study and they include documentation, archival records, interviews, direct observation, participant observation and physical artefacts (Yin, 2009). The tools that will be used in the research include direct and participant observations, informal interviews and data sheets and they will be described below:

Direct and Participant Observations

In the study observations method was used to collect information which Foundry management and Foundry workers would not willingly share (Dawson, 2002). Participant observation involves the researcher's involvement in a variety of activities over an extended period of time that enable him/her to observe the members culture in their daily lives and to participate in their activities to facilitate a better understanding of those behaviours and activities (Kawulich, 2005). Observations were done in different sections of the Foundry to understand the process entirely. There are three types of observations which include (Angrosino & Perez, 2000):

- Descriptive observation – This is when one observes anything and everything assuming that he /she knows nothing. The disadvantage of this observation is that data irrelevant to the study may be collected. At the Foundry the entire process was observed and there is some data that was collected and not used. There were instances in the Foundry when the researcher became a full participant of what was being observed especially in situations when operators in the line needed urgent assistance.
- Focused observation – This is when observations are supported by interviews in which the participant’s insight guide the researcher’s decisions about what to observe.
- Selective observation – This is when the researcher focuses on different types of activities to help delineate the differences in those activities. This method was employed in the research when the study of top castings and brake shoe holders was conducted.

Stances of the Observer (Kawulich, 2005)

Gold (1958) relates the four observation stances as follows**:**

- Complete participant – In this study the researcher became a full member of the Foundry employees to avoid disrupting normal activity. The disadvantage with this is that as a researcher, there can be a lack of objectivity. The group members may feel distrustful of the researcher when the research role is revealed, and the ethics of the situation are questionable, since the group members are being deceived. In this study the Foundry workers did not know that the information was used for research and they never found out**.**
- Participant as observer stance, here the researcher is a member of the group being studied, and the group is aware of the research activity. The researcher participated in the activities that happen at the Transnet Foundry to further understand how operations occur.
- Observer as participant stance- This enables the researcher to participate in the group activities as desired, whilst the main role of the researcher is to collect data. In this stance, the group being studied is aware of the researcher's observation activities. The researcher interacted with the Transnet Foundry workers without dictating to them how they should conduct their work.
- Complete observer - Here the researcher is in plain sight, in a public setting, yet the public being studied is unaware of being observed. This was done especially at the end of this research to understand behaviours of employees when working.

Informal Interviews

There are three types of interviews that are used in social research and they include unstructured interviews, semi-structured interviews and structured interviews (Dawson, 2002). Informal interviews were conducted in each and every section of the Foundry to understand some of the problems that may not be easy to detect by direct observation. There are three basic types of questionnaire which include closed ended, open-ended or a combination of both (Dawson, 2002). In this study an open-ended questionnaire was used along with data sheets that were formulated. Participant observation was used when the researcher wanted to immerse herself in a specific culture to gain a deeper understanding. The informal interviews were conducted during observations. Two sets of interviews were conducted, one for operators and the other for supervisors for the particular sections. Three operators were interviewed per section (process) and each of the operators gave a view of the process.

When interviews were conducted, notes were taken. The advantage with this recording method is that the Transnet Foundry employees felt they were saying something important and this allowed the researcher to add more information. The disadvantage of note taking is that it is difficult to maintain eye contact and it can be hard to concentrate on what respondents are saying and to probe them for more information (Dawson, 2002).

Data Sheets (Excel Spread sheets)

Excel sheets were used to collect the data from the mould making, casting and dressing sections. The data sheet will be designed for the specific sections where they will be used. Whenever more data is required in the study, they will be used accordingly.

The summary of data collection and analysis tools used in this particular research can be shown in Table 3-1.

Table 3-1: Summary of data collection and analysis tools

Data Source	Data Type	Data Utility	Purpose of Data
Documentary evidence	- Official records - Historical data - Email correspondence -Personal notes	- Verified data collected from the casting production line	-Assisted in determining the quality issues in the Foundry - Assisted in quantifying the losses in profit and productivity
Direct Observation	- Factory visit - Factory work - Involvement in production meetings	-Collected real time data (datasheets) -Verified context of case study	- Assisted in understanding the process and operations in the Foundry -Helped interpret data gathered from historical records
Participant Observation	- Observations, experience, events, activities	- Provided the researcher with insight on the operations though there were elements of bias due to participant observer's manipulation of events	- Assisted in collecting descriptive details about current quality processes - Helped interpret data gathered from informal interviews, and production meetings -Helps interpret causal influences
Archival Records	Service records obtained from computer files (SAP)	-Provided the researcher with broad coverage over a long span of time	-Assisted in observing trends over time

3.2.2 Data analysis tools and Techniques

a) Cause and Effect diagrams

Cause and effect diagrams will be used to conduct the root cause analysis of the various defects that occur in the Foundry. The cause and effect analysis will also be used for other unforeseen scenarios that may need to be investigated in the study.

b) Process flows

Detailed process flows will be mapped for the Foundry and for the quality department to give an indication of how the quality system is currently being managed.

c) Pareto charts

Pareto charts will be used to illustrate the impact of the casting defects on the productivity of the Foundry. The bar graphs will also be used to represent the data that will be collected from data sheets and from archived records.

d) Pie chart

Pie charts will be used to show impact and size of quality issues and defects relative to each other in the Foundry.

e) Statistical Analysis

The control charts will be used to illustrate whether the processes are in control or out of control. This will help identify the processes or machines that may need to be calibrated or re-calibrated.

f) Financial Analysis

Financial analysis will be done to give an indication of the loss which the business has incurred as a result of poor quality practises which they have employed.

3.3 Reliability

According to Yin (2009), the objective of a reliability test is to be sure that if a later investigator followed the same procedure as described by an earlier investigator and conducted the same case study all over again, the later investigator should arrive at the same findings and conclusions. The role of reliability is to minimise biases and errors in the study (Yin, 2009).

Reliability of a study can be improved by conducting tests, three of which will be described below and how they were ensured in this particular research (Trochim, 2006):

- Inter-observer reliability - There was no risk of variance from the way different observer’s view any phenomenon as this study was conducted by one researcher at the Foundry. All the views in the study are those of researcher in particular.
- Test-retest reliability - The risk of consistency in the study was ensured by conducting observations at the same section on different days and on the archived records, data collected on different days was checked to reduce variations and to eliminate all possible bias.

Parallel-forms reliability - The observed Foundry operations were being conducted by one operator at a time and this reduced the risk of parallel form.

3.3 Validity

Validity is stronger with the use of additional strategies used with observation, such as interviewing, document analysis, or surveys, questionnaires, or other more quantitative methods (DeWalt & DeWalt, 2010). Participant observation can be used to help answer descriptive research questions, to build theory, or to generate or test hypotheses (DeWalt & DeWalt, 2010). Yin (2009) describes four tests that are common to social science methods and they include:

- Construct validity – Identifying correct operational measures for the concepts being studied
- Internal validity – Seeking to establish a causal relationship whereby certain conditions are believed to lead to other conditions as distinguished from spurious relationships
- External validity – defining the domain to which a study’s findings can be generalised
- Reliability – Subsequent research be repeated with the same results

The two threats of personality bias and reactivity threat can affect the validity of research (Pannucci & Wilkins, 2011) and they will be described below.

Personality bias threat

There are many ways in which the researcher can contribute to the distortion of the research findings. These include:

- Flawed study design which could occur due to incompetent or under trained study personnel (Pannucci & Wilkins, 2011). In the study at the Foundry, the researcher with a basic understanding was used; hence no inter-observer variability was expected. This was also avoided by structuring the questions in a way that did not steer particular responses or make the interviewee understand the situation in a certain way.
- Observation bias could occur in the research especially in terms of how the information is collected, recorded and interpreted (Pannucci & Wilkins, 2011). The observer may be influenced by the supervisors dedicated to the station. In addition, the operators may work differently when they see someone observing them whilst they are working (Pannucci & Wilkins, 2011). To avoid this bias, all the data collection sheets were structured for the sections where data was not collected in the Foundry. The researcher collected the data without delegating to anyone for assistance. Three operators and a supervisor were interviewed per station. All the facts and variables were taken into consideration.

Interviewer bias could occur due to the systematic difference between how information is solicited, recorded is happens when the interviewer does not ask the same question to different people at different times (Pannucci & Wilkins, 2011). Perceptions and cultural issues of the interviewer can influence bias and as a result interview questions should be structured (Pannucci & Wilkins, 2011). In this study this was avoided and same questions were asked to all the operators and supervisors.

Reactivity bias threat

The researcher may again knowingly or unknowingly influence the setting or individuals by manipulation to achieve certain desired outcomes (Maxwell, 2005). In this study it is easy to say that operators do not care about quality principles simply by observing the quality defects that the business incurs. This threat was not expected to contribute to any bias in the research, because the researcher observed the casting process entirely and also studied the behaviour of operators under different circumstances. However it is almost impossible to eliminate the influence of the researcher (Maxwell, 2005).

4. PHASE 2: MEASURE - CURRENT STATE ANALYSIS

This phase identifies key product parameters and process characteristics and measures the current process capability (Gryna, Chua, & DeFeo, 2007) as outlined in section 2.4.1.1 of the literature review. For the purpose of this research, this will take the form of a current state (status quo) analysis. In this chapter, the general background of the Transnet Foundry business is presented. The products that are cast on the production line are described and the entire Foundry process is mapped and analysed using root cause analysis. In this way, key product parameters and process characteristics are identified.

4.1 Introduction to Transnet Foundry

Transnet Engineering's Foundry Business has a long history dating back 50 years. The main objectives of the Foundry are to cast top centre castings, frames, bolsters, wedges, side frames, couplers, draw gears, brake shoe holders. Currently the Foundry business is being upgraded to resume its competitive role in South African Rail Industry.

The Foundry business operates from two sites, one in Tshwane at Koedoespoort and a much larger facility in Bloemfontein. The two facilities have the ability to produce any castings a customer may require. The big castings that are manufactured at the Foundry include the Top Centre Casting (TCC), E-Type coupler, Pedestal and the F-Type coupler. Smaller castings include centre pieces, brake shoe holders and front stops. Smaller castings are casted by using the green sand and the bigger castings are casted using chemically bonded sand. The Foundry process flow for operations can be seen in Figure 4-1.

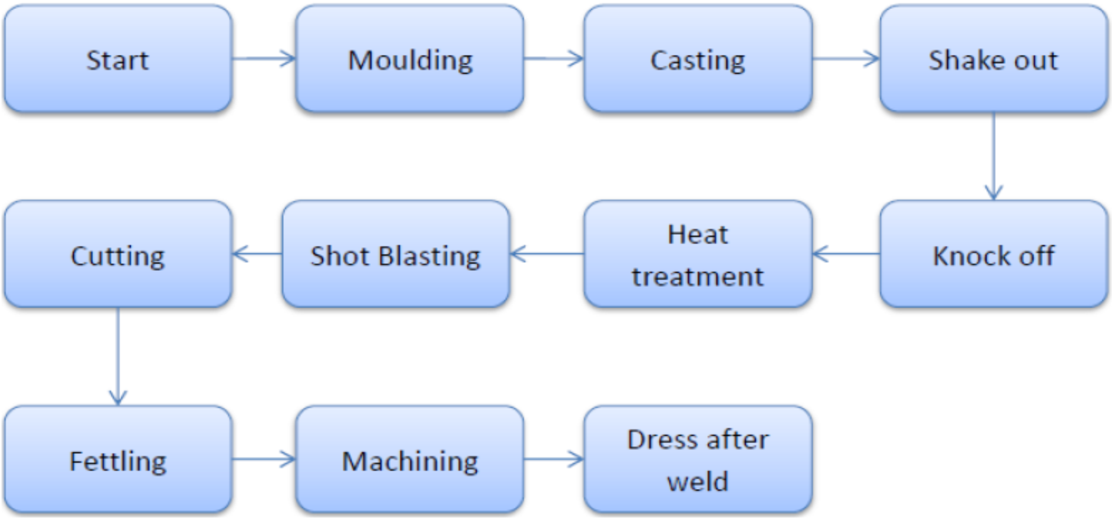


Figure 4-1: Foundry operations process

The Foundry process has been outlined in Figure 4-1 and data was not collected for all the processes as some activities in the business have been outsourced and they include knock off, shot blasting, cutting, fettling and machining. In this study not all the processes will be analysed, as some activities have been outsourced and this poses a challenge in terms of the control of the process. The Transnet Foundry focuses on moulding, casting, heat treatment and dress after weld which is the repair of castings after machining has been done. In the casting process, temperature of molten metal and speed of pouring should be measured.

4.2 Product Description

In the research two castings are going to be analysed and they include the brake shoes holders and the top centre castings.

4.2.1 Top Centre Castings

Top centre castings are manufactured from chemically bonded sand. Chemically bonded sand is a mixture of silica sand, resin and catalyst. Chemically bonded sand is used for the manufacture of bigger sized castings and they all undergo the same process. The other difference in the chemically bonded sand area and green sand area is that the chemically bonded sand area is a very manual and labour intensive process.

In the chemically bonded sand area, core making and mould making are manual processes. In the green sand area, cores are purchased from external suppliers. Handling becomes a challenge where cores usually break before and during production. Cores are combined with bottom and top mould and molten metal is poured into the mould. The supervisor in the chemically bonded sand section does the mixing for resin, catalyst and sand on three different types of machines which include 5, 10 and 25 Ton machines. Figure 4-2 illustrates the casting steps for the top centre castings in the chemically bonded sand area.

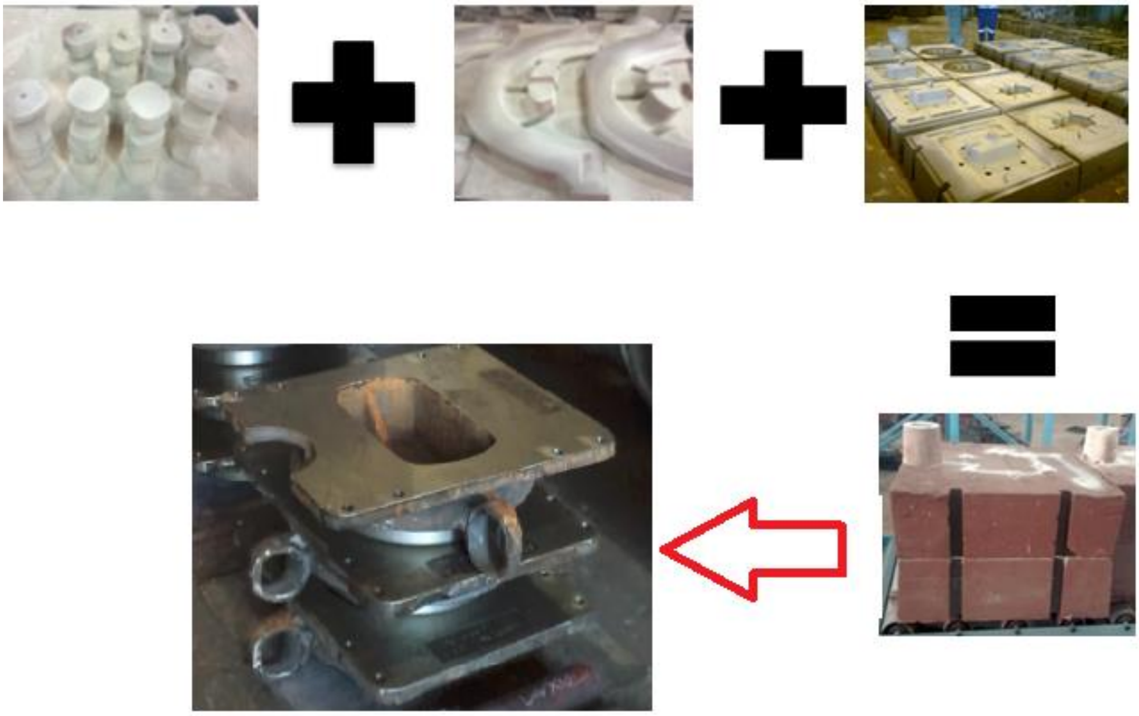


Figure 4-2: Manufacture of Top centre Casting

4.2.2 Brake shoe holders

Brake shoe holders are made from Green sand. Green sand is made of wet sand that is used for moulding. The name comes from the fact that wet sands are used in the moulding process (Brown, 2000). In the green sand plant, starch and a binder are mixed with silica sand. In the green sand plant, mixing of the starch and binder is done automatically. The mixture is taken to the laboratory before moulding is done to ensure that the mixed sand has the correct moisture and chemical properties. When the sand passes the test, it is moved through conveyor belts to the moulding line.

There are instances when the sand gets moulded even though it did not pass the quality test due to pressure from customers and the urgency of meeting monthly targets. In the moulding process, the sand is dispensed into moulding boxes containing a pattern that is the replica of the product to be casted. Figure 4-3 shows a pattern for a brake shoe holder.

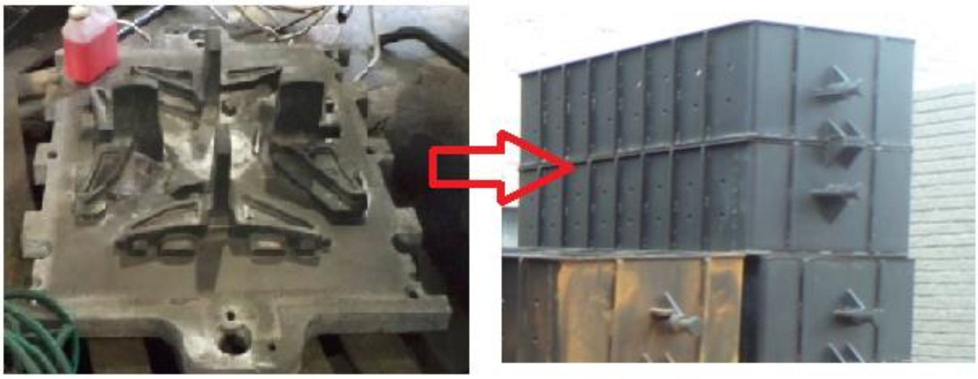


Figure 4-3: Brake shoe holder and pattern

The Foundry business comprises of operations, logistics, sales and customer departments. The entire Foundry process that incorporates customer, sales, logistics and operations can be seen in Figure 4-4. Quality issues can be studied in any of the departments and for this research, focus will be directed on the operations and final customer departments.

4.2.3 Differences in Top Centre Casting (TCC) and Brake Shoe holders (BSH)

The products that are studied are very different and the differences will be outlined in Table 4-1. The reason why both products were chosen to be studied is because demand for castings is high and they contribute more to the business revenue.

Table 4-1: Differences in TCC and BSH

Product/Casting Type	**Type of sand**	**Machine used**
Top centre casting	Chemically bonded sand	5 ,10,25 ton
Brake shoe holders	Green sand	Green sand plant

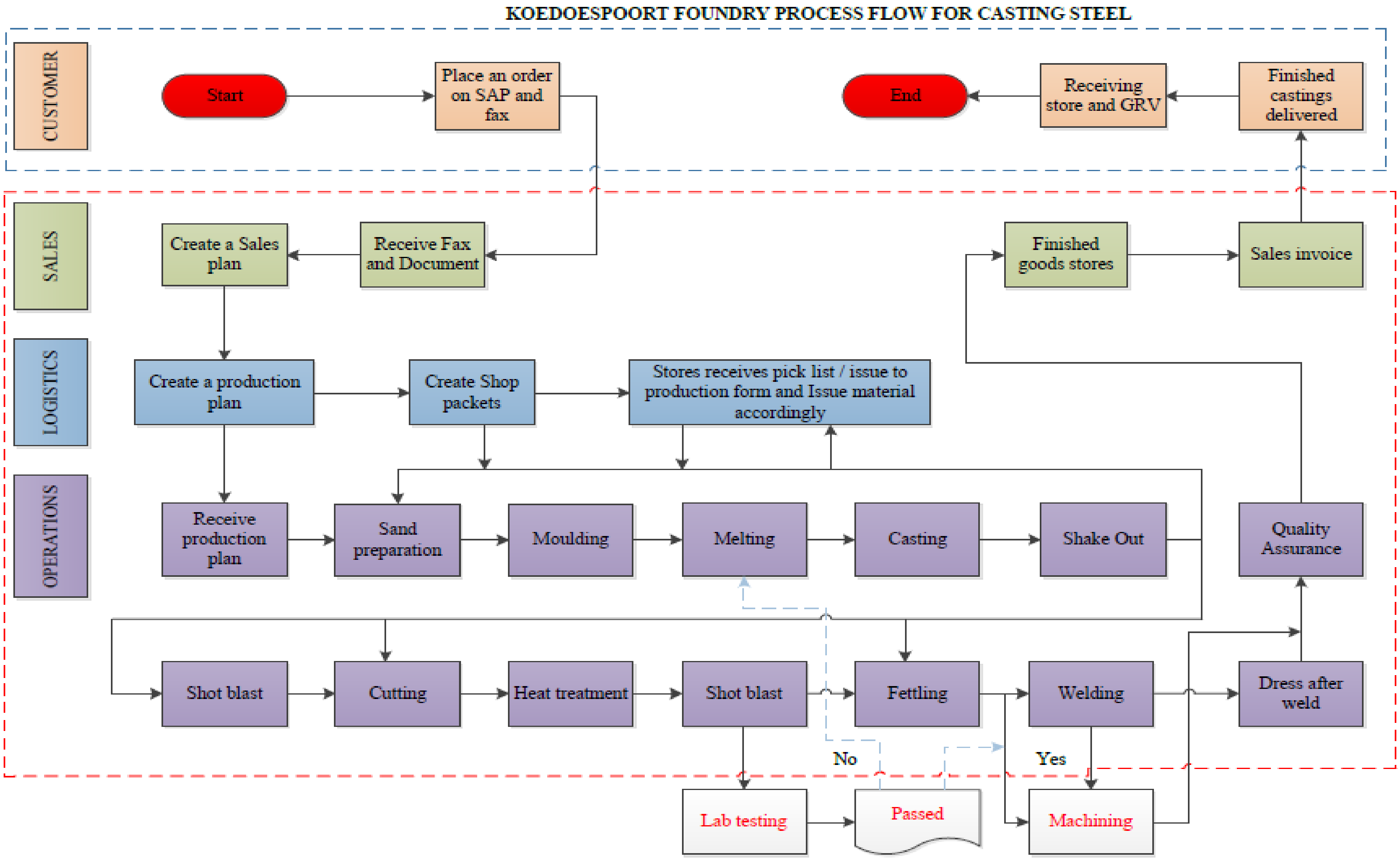


Figure 4-4: Foundry process flow (Transnet, 2015)

4.3 Foundry Process description

The Foundry process will be described for the green sand area and the chemically bonded sand area. Root cause analysis will be conducted for the different sub processes.

4.3.1 Sand Preparation

Sand preparation involves preparing the sand for moulding in the green sand and chemically bonded sand area. Preparation of sand for brake shoe holders is done in green sand area and for the top centre castings it is done at the chemically bonded sand area. Brake shoe holders and top centre castings are used in all the wagons, coaches and locomotives that are manufactured at Transnet and for their maintenance as a result these castings are high demand products.

4.3.1.1 Green Sand Preparation

Green sand is not green in colour but wet in the sense that it is used in a wet state. It comprises silica, chromite or zircon sand (75-85%), bentonite clay (5-11%), water (2-4%), inert sludge (3-5%) and anthracite (0-1%) (Land, Voigt, Cannon, Goudzwaard, & Luebben, 2002). The Transnet Foundry uses silica sand. Using green sand has numerous advantages which include affordability and availability. Green sand can be recycled and the manufacturing cycle is short and working efficiency is high. The Foundry reclaims sand. Sand reclamation is the process of cleaning previously used sand so that it can be reused. The tests that are conducted daily on green sand by the laboratory staff are shown in Table 4-2. The tests that should be done daily at the Foundry are specified by the Foseco handbook (Brown, 2000)

Table 4-2: Comparison of daily tests

Foseco Standard tests	Tests done at Transnet Foundry
Compactability	Compactability
Moisture	Permeability
Specimen weight	Green strength
Permeability	
Green compression test	
Dry compression strength	
Methylene blue clay content	
Total clay and Active clay	
Loss Of Ignition(LOI)	
Volatile	
Green shear	

In the testing sheet at Foundry temperature, total clay, active clay, LOI, volatile, moisture, green shear are not measured as there is no provision for the parameters on the testing sheet. Failure to conduct all the necessary green sand tests earlier in the process leaves room for defects to propagate further in the process. The green sand testing procedure can be seen in Figure 4-5.

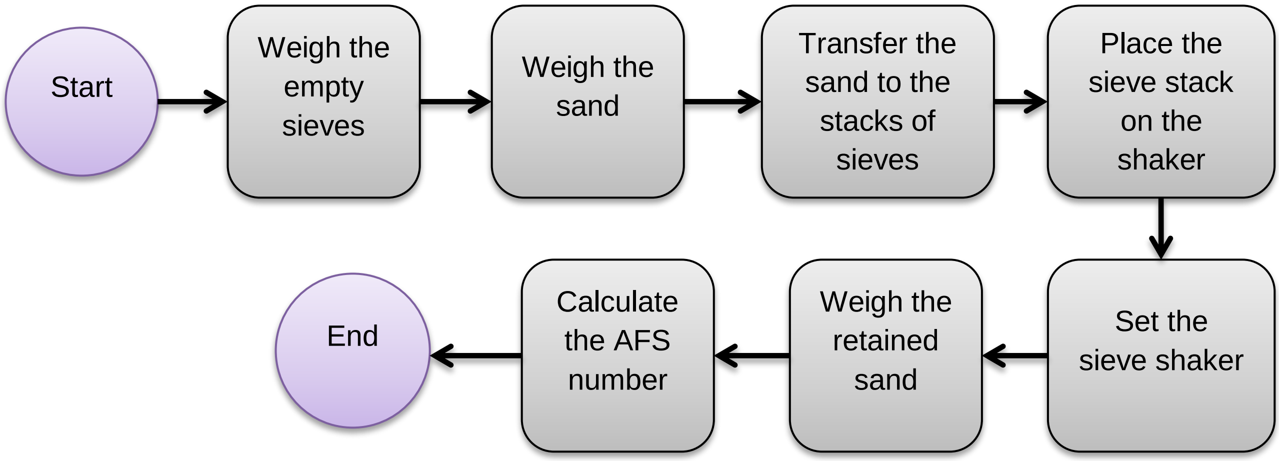


Figure 4-5: Sand testing at Transnet Foundry

Types of green sand tests

i. **Compactability tests -** Compactability test indicates how wet or dry the green sand is and helps control most common green sand defects. It is directly related to the performance of the green sand in the moulding operation (Brown, 2000).

ii. **Moisture Determination -** This test is used to determine the percentage of moisture in the moulding sand (Brown, 2000).

iii. **Compression strength -** Green compression strength indicates the maximum compression stress the sand mixture is capable of sustaining and is used to control the rate of clay addition to the green sand system (Brown, 2000).

iv. **Permeability -** Permeability is a test of the venting characteristics of a rammed green sand mould (Brown, 2000).

v. **Methylene Blue clay test-** This test measures the amount of live clay present in a sample of moulding sand (Brown, 2000).

Comparison of weekly tests

Weekly tests must be done at the Foundry as specified in the Foseco Manual (Brown, 2000). Transnet Foundry also calculates the AFS and Fines whilst other tests are not done.

Table 4-3: Comparison of Weekly Tests

Standard tests (Brown, 2000)	**Tests done at Transnet Foundry**
AFS or 25 Micron clay content	AFS
Screen analysis	Fines
Total combustibles (LOI)	
Volatiles	
Available bond	
Working bond	
Muller efficiency	

As a result of failure to measure all the green sand parameters before moulding, defects occur consequently.

Root cause analysis

A root cause analysis was conducted and the information used was obtained from observation of the green sand preparation process and the historical records that are available from the sand testing laboratory analysed. The root cause analysis was done to understand why defects arise from sand testing. This can be seen in Figure 4-6.

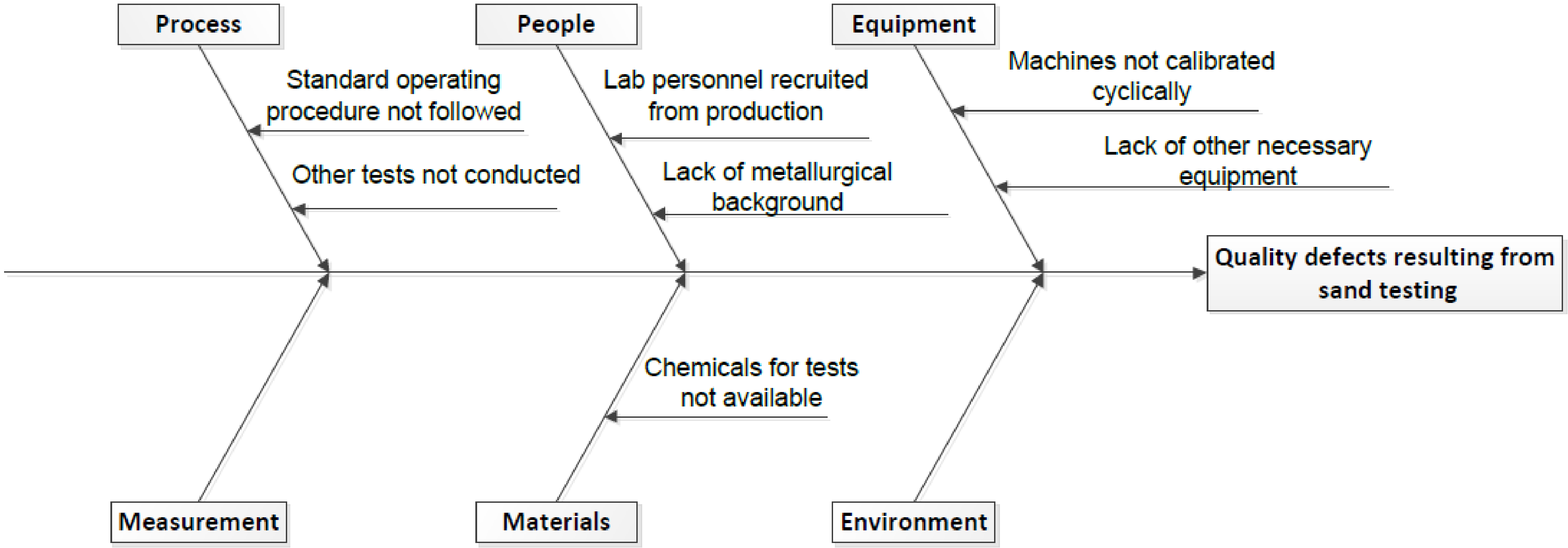


Figure 4-6: Root cause analysis sand preparation

4.3.1.2 Chemically bonded sand preparation

For chemically bonded sand, a binder, sand and a hardening chemical are mixed together to ensure that the binder and hardener react. The reaction that occurs is sufficiently slow to allow the sand to be formed into a mould or core which continues to harden further until strong enough to allow a casting (Brown, 2000). Clean dry sand is mixed with binder and a catalyst usually in a continuous mixer (5 Ton, 10 Ton and 25 Ton).The mixed sand is vibrated or hand rammed around the mould pattern or into a core box causing the binder and catalyst to react, hardening the sand (Brown, 2000).The standard tests that should be conducted on chemically bonded sand include Sieve, Mesh, % Retained Factor, Product, %Fines, Bulk density and pH (Brown, 2000). Transnet Foundry does not conduct these tests.

4.3.2 Mould making

i. Green sand moulding

In green sand moulding, the sand is moved from the green sand plant through a conveyor belt to be dispensed to the mould patterns for brake shoe holders. There is a requirement that patterns should be kept in a clean environment, however the Transnet Foundry does not have an in-house mould pattern shop and as a result patterns are stored inside the Foundry. The dust damages the mould patterns and the Foundry currently does not have go and no/ go gauges for measuring if the bushes and pins in the pattern are still within specification. Maintenance of patterns is an outsourced service and this sometimes causes a delay in production as the control during pattern repair lies with the supplier.

From observations at the green sand moulding area, the quality issues that have been identified with green sand moulding include challenges in the process, people, equipment, measurement, materials and the environment. In the process, it has been highlighted that the quality is not inbuilt into the process. Quality assurance is a responsibility of the operators and since the operators are more focused on the volumes of the moulds that they make, they tend to overlook some of the factors that could cause defects in the casting later in the process. The operators that work in the green sand moulding line are not specialised although given training. They are regularly rotated to other sections to ensure that they are multi skilled. The downside of this multi-skilling is that it compromises the required expertise especially needed in moulding. Mould making is a specialised trade. The process for moulding green sand can be seen in Figure 4-7.

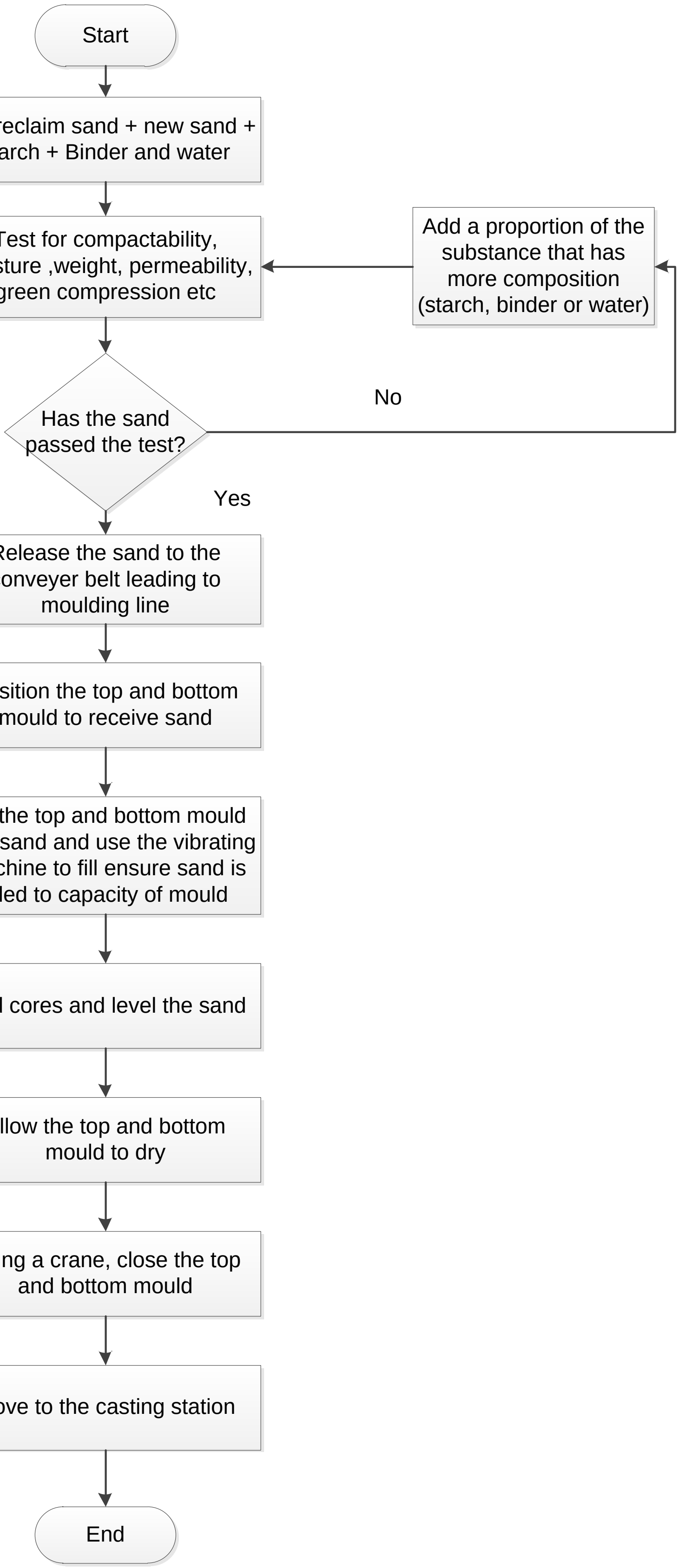


Figure 4-7: Green sand moulding process

The root cause analysis for the reasons why the defects occur in green sand moulding can be seen in Figure 4-8.

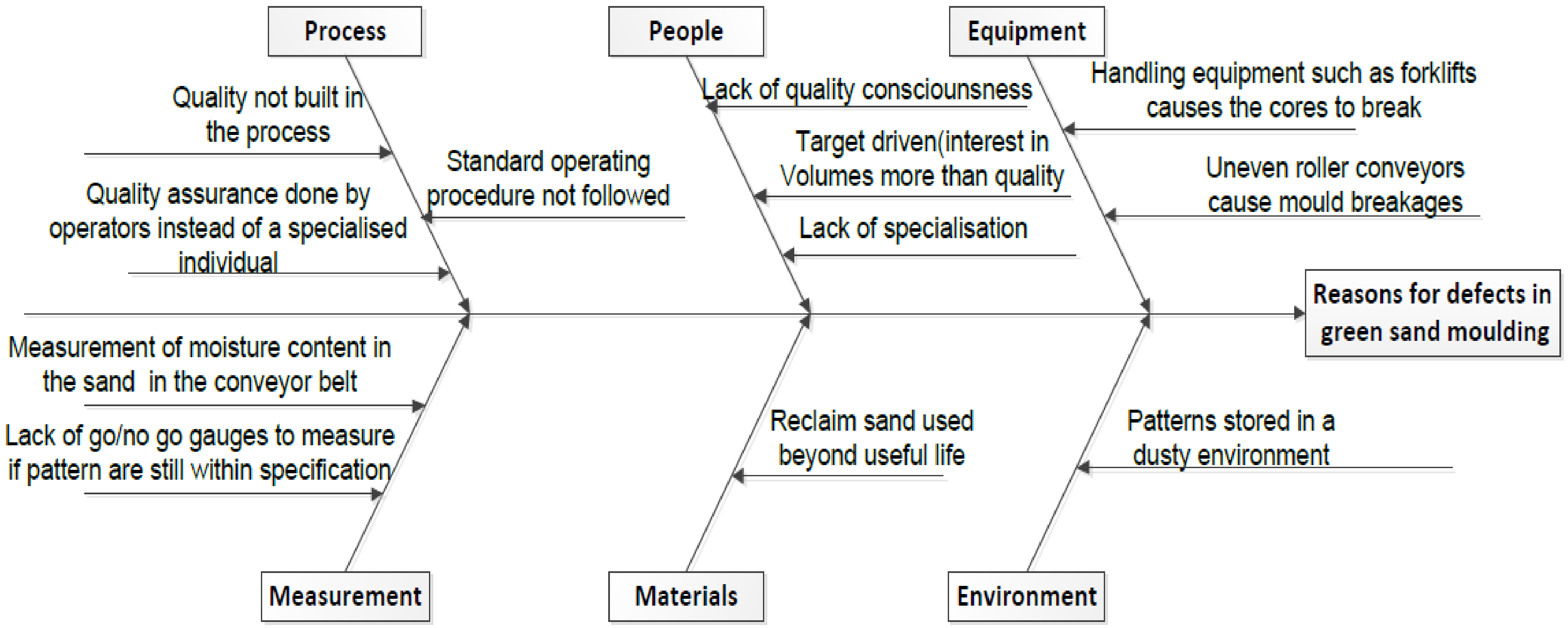


Figure 4-8: Root cause analysis for defects in Green sand moulding

Defects occur in green sand moulding because reclaim sand is over-used beyond its useful life.

ii. Chemically bonded sand moulding

There are three machines that are dedicated to the moulding of chemically bonded sand in the foundry and they include 5 ton, 10 ton and 25 ton mixing machines. From the process, it is evident that quality inspection is not done during the moulding of the sand. The supervisor or the artisan who has been trained to mix the resin and catalyst with sand ensures they adhere to the specification though it cannot be measured. It is done through experiential intuition. The operators that are hired in the chemically bonded sand area are a mixture of senior technical workers and artisans in training. Employees in the Foundry are continuously rotated and this prohibits specialisation in one discipline. It is imperative that employees specialise, as mould making is a skill and continuous training of operators in their trade should be fostered. The process for moulding chemically bonded sand can be seen in Figure 4-9.

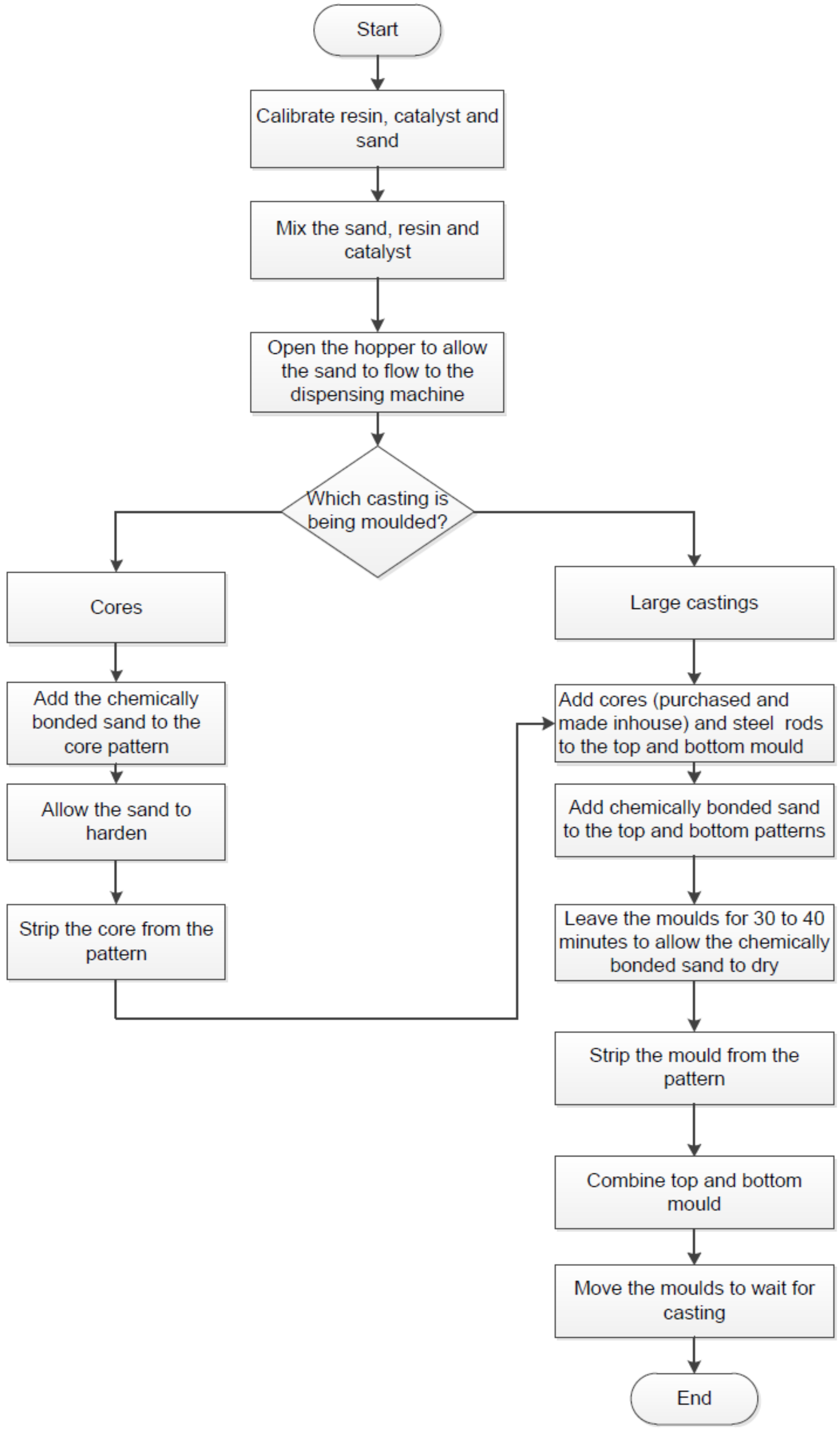


Figure 4-9: Chemically bonded sand process

Root cause analysis

Observations at the chemically bonded sand process indicated that the major challenge with the process is its labour intensive nature. Further observations showed that quality assurance is not emphasised. The operators in the chemically bonded sand section are target driven. They are more concerned with the volumes they put out at the end of the shift than the quality of the products. The other challenges observed which have a negative bearing on the product quality is the heavy casting weight of the moulds. Moulds are heavy and can only be moved by means of an overhead crane. The root cause analysis for how defects occur at the chemically bonded sand moulding section can be seen in Figure 4-10.

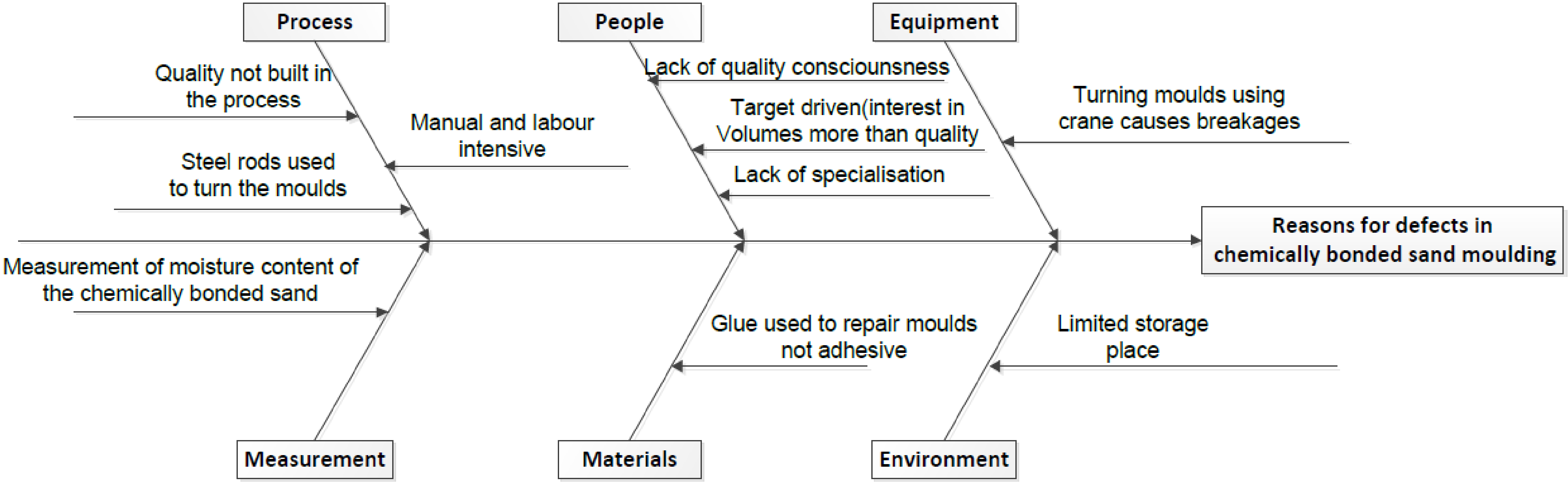


Figure 4-10: Root cause analysis for how defects occur in chemically bonded sand moulding process

4.3.3 Melting

The melting section is where scrap metal is heated in the furnace until it becomes molten metal. There are other chemical additives that are added to ensure the quality of the molten metal meets the required chemical composition specification. Scrap metal that is used is purchased from outside suppliers such as NN and Sakhubuhlobo metals. The Foundry scrap metal that comes from the risers and runners is also supposed to be used for melting. However there are irregularities with the collection of scrap in-house. There are cases when other metals that are not steel are also melted because the suppliers were rushing to provide the required tonnage and did not fully comply with the required steel specification. Other scrap that is melted comes from Transnet Engineering's other businesses. The molten metal that is used for brake shoes and top centre castings is the same. The difference is in the mould (green sand mould or chemically bonded sand mould).

i. Induction furnace

In the induction furnace quality can be ensured by using the specification for scrap that complies with the Transnet scrap standard. The process for melting can be shown in Figure 4-11.

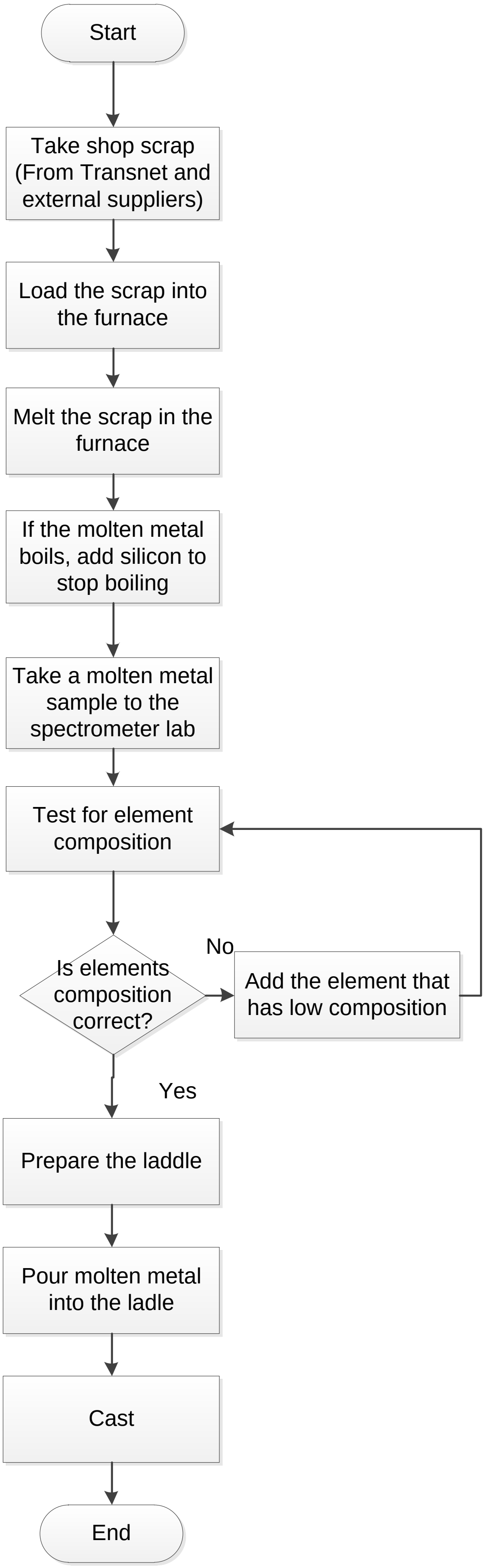


Figure 4-11: Melting process

ii. Spectrometer testing

Before spectrometer testing can be done on the molten metal, it is imperative that the spectrometer machine is calibrated to reduce or eliminate variations in the results of the composition of chemistry. The process for spectrometer testing can be seen in Figure 4-12.

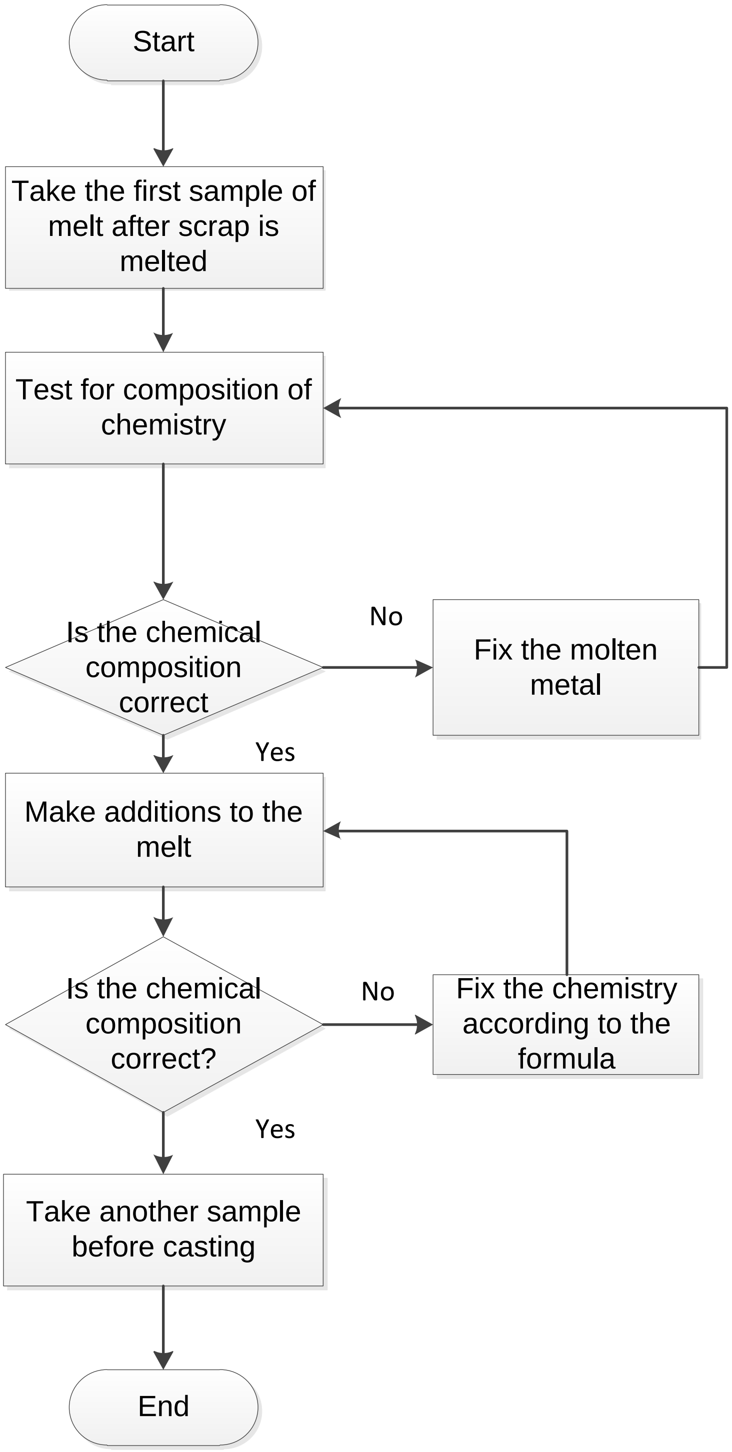


Figure 4-12: Spectrometer testing

Melting defects

The root causes for the defects that occur in melting can be seen in Figure 4-13.

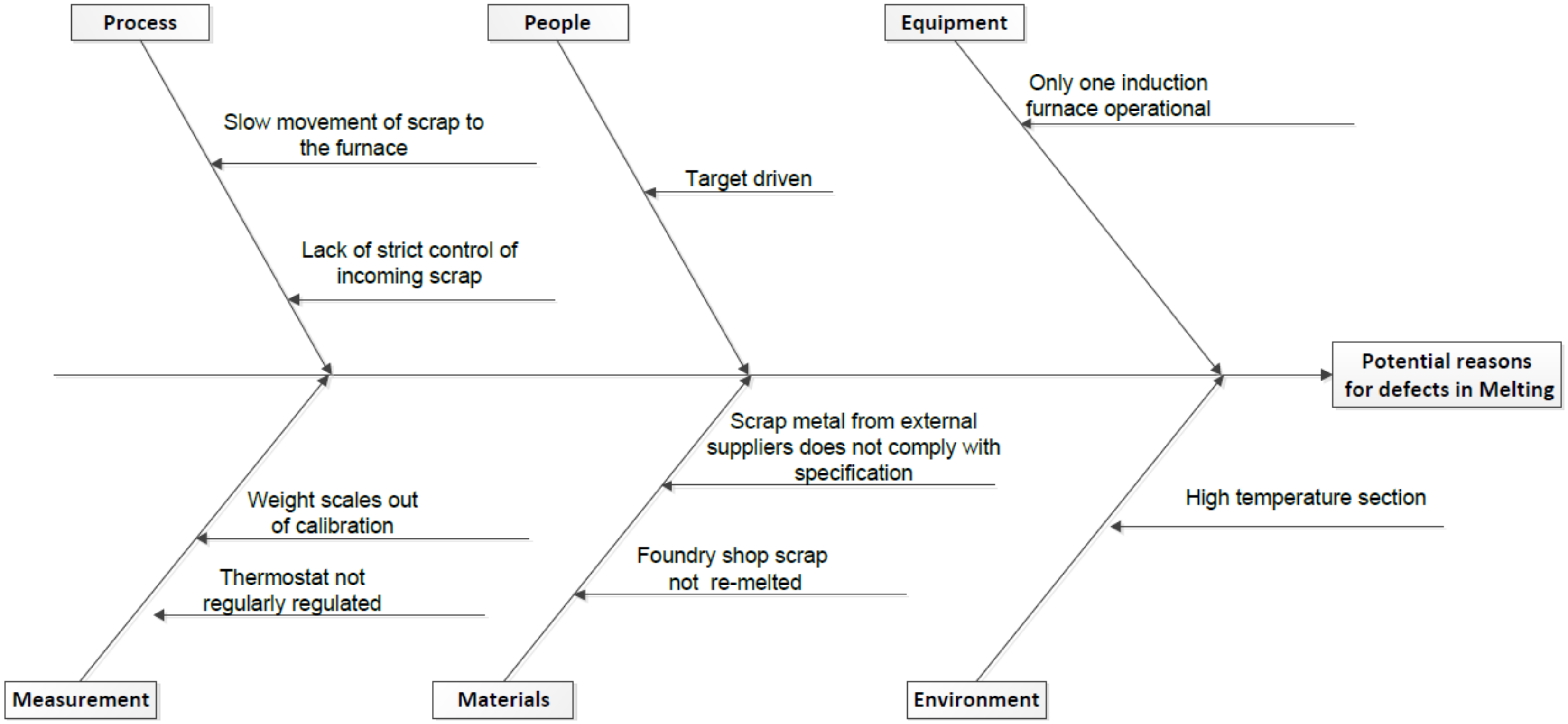


Figure 4-13: Root cause analysis

4.3.4 Casting

In preparation for casting, the ladle to be used is prepared. Preparation of the ladle involves cleaning to ensure that all the molten metal that was contained the previous day is removed. A new nozzle is inserted and the operator checks to ensure that it is well sealed. Complete sealing will ensure that the molten metal does not leak. After the ladle has been cleaned, it is taken to the burner where it will be heated until it reaches a temperature of 950 degrees Celsius.

Before pouring into the mould, the molten metal is poured into the ladle and it is important to ensure that the stopper has no cracks and that all the nuts are tight. It is also important to ensure that the slide works correctly. During pouring, the molten metal is poured into the moulds for top centre casting and brake shoe holders. A sample of molten metal is taken just before casting begins. The casting process can be shown in Figure 4-14.

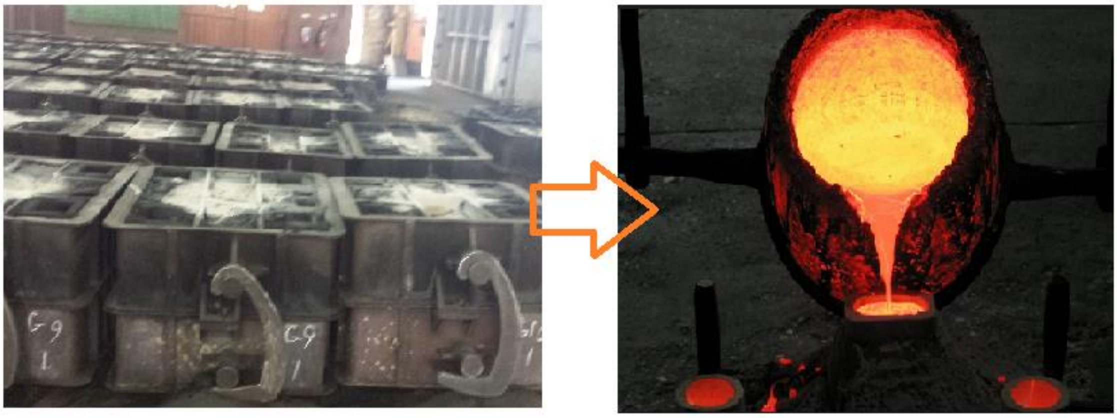
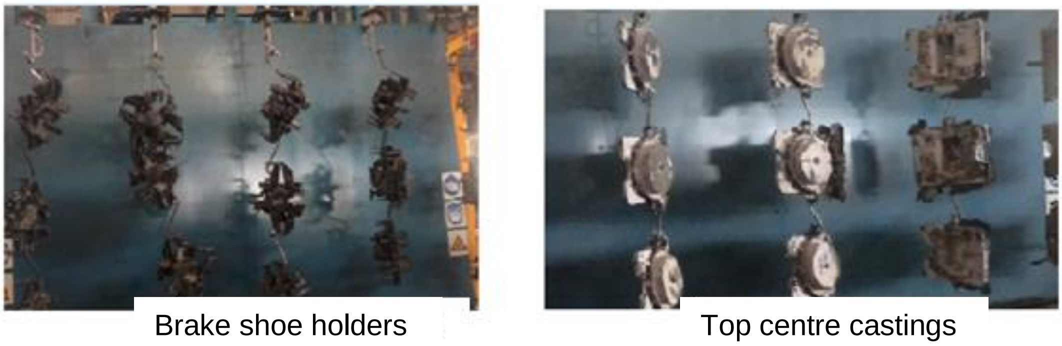


Figure 4-14: Casting

4.3.5 Shot blasting

Shot blasting involves removing the sand from the actual casted component. This process cleans the surface of the casting so that it is easier to do final surface finishes on it. This can be shown by Figure 4-15. Inside the shot blasting machine, small iron balls are thrown at the casted component at a high velocity and this action causes the sand and the other dirt on the surface of the component to be removed.


Brake shoe holders

Top centre castings

Figure 4-15: Shot blasting

In the shot blasting booth, the smaller castings are hooked and they are shot blasted. For smaller castings such as the top centre castings, more than one brake shoe holder is hooked. For larger castings such as the top centre castings, more than two castings are hooked. The castings are shot blasted until all the sand is removed to enable cutting of risers and runners. Castings undergo two cycles of shot blasting to ensure that the surface is clean. Quality defects on the surface of the casting can be easily seen after the second shot blasting process.

4.3.6 Shakeout

Shakeout involves removing the sand from the casted component. There is a shakeout machine that is used to remove sand from brake shoe moulds that is connected to the green sand plant. The sand that is removed from the casting goes up the conveyor belt to be used again. The machine vibrates and by so doing the sand is removed from the casting. Not all the sand is removed from the casting by simply shake out. For bigger casting, another machine called the bobcat is used to aid in breaking the sand from the mould. The removal of sand is a manual and time consuming process.

4.3.7 Dress to gauge

Disk grinders and pencil grinders are also used to ensure that the surfaces of the castings have an even finish. This has been outsourced to external suppliers who have the capability.

4.3.8 Dress after weld

Welding is also done to repair some of the castings that may have defects especially holes and this process is commonly known as dress after weld. Not all castings undergo dress after weld. It’s only those castings that have defects that can be fixed by welding. When welding has been done, there is a need for the welded surface to be ground so that welded material uniformly binds to the surface of the casting.

4.3.9 Machining

Machining is a process that is used to finish the surface of the casting and this can be shown by Figure 4-16. The Transnet Foundry does not have an in-house machining facility and as a result, the machining function is outsourced. The quality control is an outsourced function making it difficult to control.

Figure 4-16: Machined top centre casting

Quality in the Foundry process is measured almost at the end of the process. However the Foundry process from sand preparation to machining requires that quality be monitored and controls put in place to ensure that quality defects do not pass from one process to the next.

4.4 Casting Defects

The major defects that were identified as causing problems in the Foundry include porosity, sand inclusions, cross joints and burst outs. Root cause analysis was done on each of the defects to find out what really prompts these defects to occur.

4.10.1 Porosity

The root cause analysis for porosity can be seen in Figure 4-17.

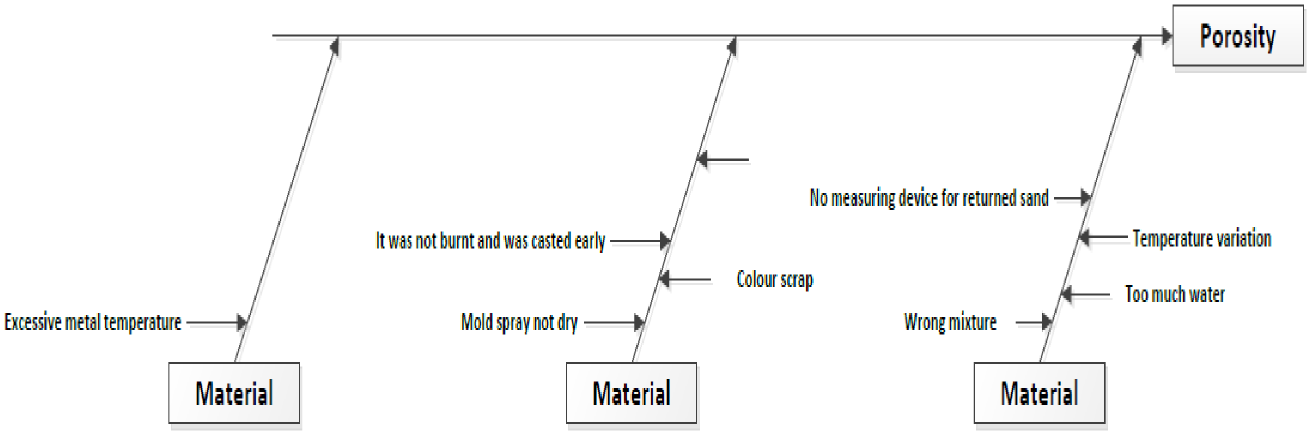


Figure 4-17: Porosity

4.10.2 Sand inclusions

Sand inclusions were identified as another of the major defects that occur. The root cause analysis for sand inclusions can be seen in Figure 4-18.

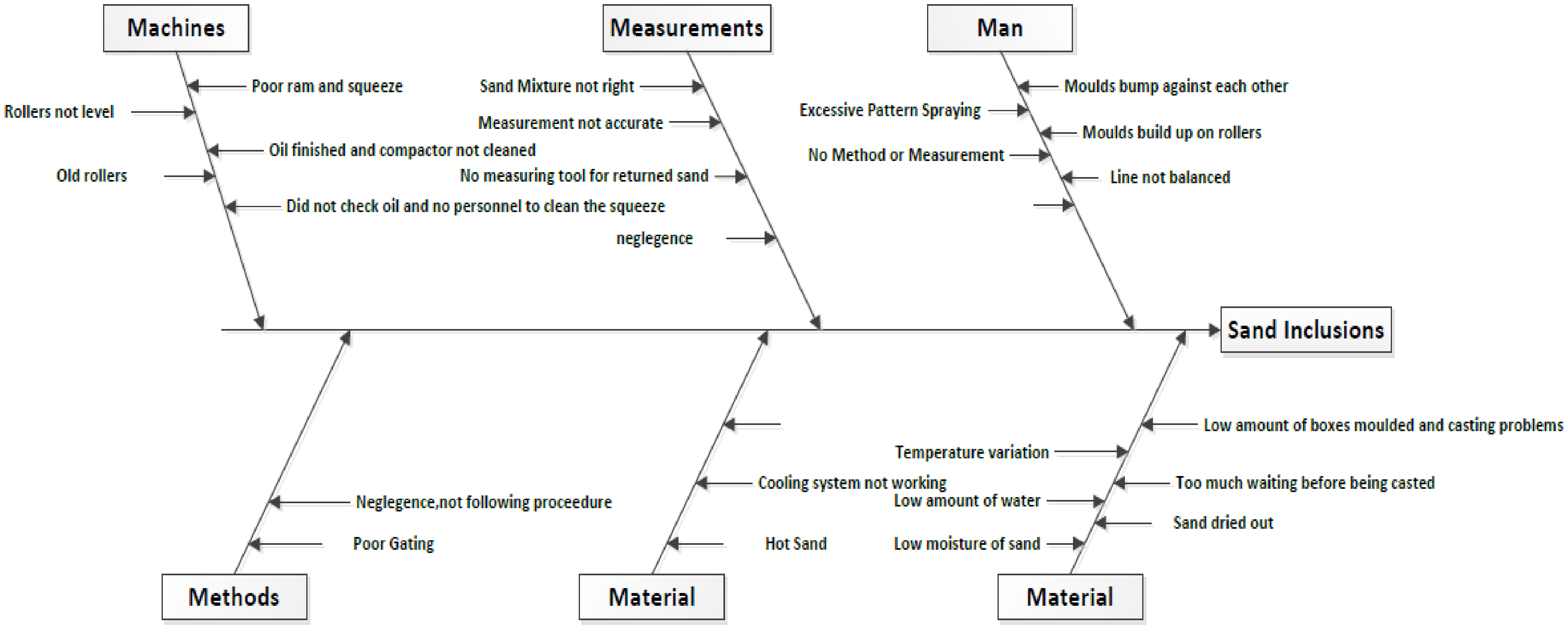


Figure 4-18: Sand inclusions

4.10.3 Burst out

The other prevalent defect in the Foundry is the burst out and the root cause analysis can be seen in Figure 4-19.

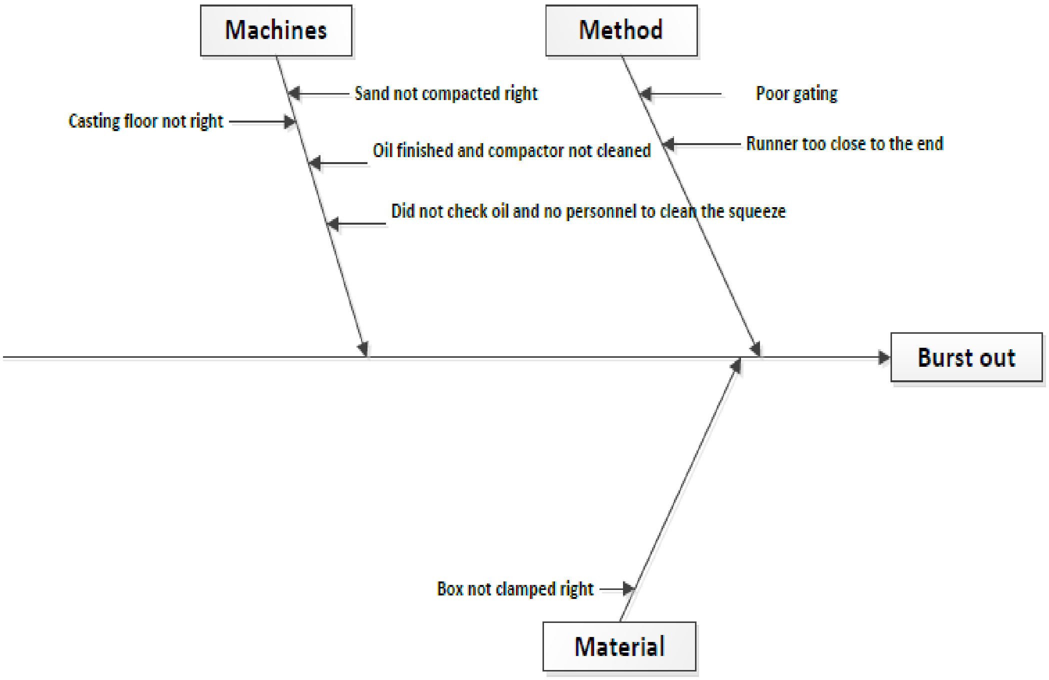


Figure 4-19: Burst out

Producing defective products has a financial impact on the business. Producing castings that are going to be thrown away especially after being processed causes the company to lose potential sales that could have been made. The losses that are made when defective products are produced include labour cost, cost of manufacturing, opportunity costs and wasted raw materials.

4.5 Summary of quality issues

The summary of key quality defects identified in the research were tabulated in Table 4-4 and compared with the ones that were identified in existing literature.

Table 4-4: Summary of quality issues

Process	Key Quality Issues	Reference in Literature
Sand Preparation- Green sand	- Not all green sand tests conducted. - Lack of metallurgical background. - Standard operating procedures not followed. - Reclaim sand used beyond useful life.	Section 2.2.1
Sand Preparation- Chemically bonded sand	- Not all chemically bonded sand tests are conducted. - Quality not built into the process. - Method of turning moulds. - Lack of quality consciousness.	Section 2.2.2
Mould making – Green sand	- Quality not built into the process. - Quality assurance not undertaken. Standard operating procedures not followed. - Handling of equipment. - Lack of measuring equipment such as go/no/go gauges.	Section 2.3.1
Mould Making- Chemically bonded sand	- Manual and labour intensive process. - Methods for turning moulds.	Section 2.3.1

	- Measurement of moisture. - Lack of specialisation. - Lack of quality consciousness.	
Melting	- Non-compliance of Scrap metal from external suppliers. - Weight scales incorrectly calibrated/ out of calibration. - Thermostat not regulated.	Section 2.3.1

The quality issues that have been identified in Table 4-4 indicate the problem statement is relevant as there are quality issues in the Foundry which need to be identified and improved accordingly. The quality issues that have been identified were also identified in the Literature review in section 2.3.1.The most common quality defects as identified in the literature review in section 2.3.2 were also identified in the Foundry and they can be seen in Table 4-5.

Table 4-5: Quality defects summary as identified in the Foundry

Casting defects	**References in Literature**
Porosity	See Section 2.3.2 in Literature review (Alena, Marianna, & Dana, 2010)
Sand inclusions	
Burst out	
Short cast	

4.6 How Quality is monitored in the Foundry

In some processes in the Foundry there is a way in which quality is monitored and these methods of tracking quality are outlined below in Table 4-6. In summary, the current state of the Foundry has been illustrated and the next chapter will show the data collected for all the activities.

Table 4-6: Methods of monitoring quality

Process	**Key Product Parameters**	**Process Characteristics**
Green sand preparation	AFS	**AFS Grains Fineness Number** is defined as the measure of the average size of grains in sand. Check if it complies with specification AFS (50-60) for return sand and for new sand AFS (45-55).
	Fines	**Fines** – Fines are defined as the percentage of sand and clay content. Fines content specification is 2% maximum for return sand and 1% maximum for new sand.
Green Sand Moulding	Mould hardness	The Green sand quality is monitored by observing the physical defects on the castings. Hardness tests are also done on the 10th mould of each batch that is being manufactured.
Chemically bonded sand moulding	Broken moulds	Visual inspection is done to ensure that there are no cracks in the mould or any other breakages.
Melting	Chemical composition	To ensure the quality is acceptable, ensure scrap metal is dry and the spectrometer analysis is done to ensure chemical composition of additives is within specification. The temperature of the melt should reach 1700degrees Celsius
Heat treatment	Heat treatment curve and temperature and time	In the heat treatment oven there is a chart that is used to control the quality.
Dress after Weld	Castings that gauge	To ensure that castings that are shipped to customers are within specification. go/no/go gauges are used.

5. PHASE 3: ANALYSE - DATA COLLECTION

This phase analyses past and current performance data to identify the causes of variation and process performance and the steps as described by (Gryna, Chua, & DeFeo, 2007) are given below:

- Plan for data collection - This has been outlined in Chapter 3.
- Collect and analyse data – This chapter presents the data collected from historical records, company records and from direct observations. Information from informal interviews was also applied. The following chapter will present data analysis.

5.1 Methods of data collection per process

The summary of the data that was collected for the processes that are still conducted at the Foundry were tabulated in Table 5-1. Some of the activities as described in the Foundry process in Figure 4-1 have been outsourced and as a result their data could not be collected.

Table 5-1: Summary of collected data per process

Process	Data Collected	Method of collection	Purpose for collection
Sand preparation	Green sand chemically bonded sand records and the grains fineness number. Focus was on average grain size and fines content.	Laboratory records	Assess when the parameters measured were correct or incorrect as per specification and the effects on casting quality
Green sand preparation	Green strength, Compactability, permeability, Live clay, volatiles and LOI	Laboratory sand testing records	To check if all the sand properties are within specification before moulding is done
Chemically bonded sand	AFS and Fines	Foundry records	Assess if the parameters were in or out of specification
Mould making	Total number of moulds made, broken moulds, hardness of moulds if non-compliant with specification	Data records from the Foundry moulding line	Assess if the hardness of moulds was compliant with specification and the ratio of broken moulds made

Melting	Spectrometer lab data for chemical composition of carbon, Manganese, Silicon, Sulphur and other metals	Data records from Spectrometer labs	Assess if the chemical composition of molten metal was within specification to ensure that final casting is correct
Casting	Number of correctly casted products as opposed to defective ones with less metal(short cast)	Data sheets were created	To ensure that pouring of molten metal into moulds was undertaken correctly
Dress after weld	Completed castings inspected using go/no go gauges and the ones that do not gauge are recorded and the accepted ones are also recorded	Data was collected from Foundry records	Assess how many of the castings gauge and how many are defective and need to be scrapped
Heat treatment	Completed heat treatment curves are used	Data was collected from Foundry records of the heat treatment ovens	Assess if the heat treatment curve came out and if the curve is obtained, a reheat is done to ensure that the castings are strengthened

5.2 Data collection per process

Data was collected for the different processes in the Foundry and details of the observations will be tabulated and compared with specification.

5.2.1 Sand preparation

Data records for green and chemically bonded sand were checked especially for instances when it was compliant and non-compliant with specification so as to assess how that affects the quality of castings in the process. The size distribution of the sand affected the quality of the castings. Course grained sands allow metal penetration into the moulds and cores giving poor surface finish to the castings (Brown, 2000). Fine grained sands yield a better surface finish but need higher binder content. Moreover, the low permeability may cause gas defects in the castings (Brown, 2000). Table 5-2 shows the specification of sand with which the Foundry sand tests should comply.

Table 5-2: Sand specification (Brown, 2000)

Sand Property	**Specific parameters**	**Reason**
Grain fineness number	50-60 AFS	Yields good surface finish at low binder levels
Average grain size	220-250 microns	
Fines content	2% Max	Allow low binder level to be used
Clay content	0.5% Max	Allows low binder levels
Size spread	95% on 4 or 5 screens	Gives good packing and resistance to expansion defects
Specific surface area	120-140cm2/g	Allows low binder levels
Dry permeability	100-150	Reduces gas defects

5.2.1.1 Return sand

Return sand is recycled sand from the casting process. Data was collected from January to June 2015. Data is supposed to be collected on a daily basis but the technicians working at the sand laboratory sometimes do not test the sand as prescribed by the standard operating procedure. It was discovered that data was not collected regularly and as a result, if there are problems with the return sand, much of the defects pass through and they cause defects in final castings. The results in Table 5-3 shows a portion of the observations for return sand data and the rest of the complete table is shown in Appendix 12-1 in Table 12-1 and a sample size of 24 observations was done. When the fines exceed 2%, defects are likely to occur. For instances in the observations where the fines were recorded to be below 2% it was marked as true and where fines exceeded 2% it was marked as false.

Table 5-3: Return Sand Observations

Date	Shift	AFS	AFS Spec	Fines%	Fine Content- 2% Max
			(50-60)		
15/01/2015	Day	41.82	FALSE	0.92	TRUE
22/01/2015	Night	45	FALSE	0.66	TRUE
23/01/2015	Day	44.75	FALSE	0.56	TRUE
26/01/2015	Day	44.1	FALSE	0.96	TRUE

5.2.1.2 New sand

New sand that has been purchased from suppliers is tested to determine if the AFS and Fines are within specification. The portion of the new sand data can be seen in Table 5-4. The AFS number and the percentage of Fine will be checked for return sand to see if they comply with the specification. Table 5-4 shows that the AFS number was below specification for the observations recorded and the rest of the data can be seen in Appendix 12-2 in Table 12-3 and a sample size of 40 was analysed. Data was collected for a period of six to seven months. Table 5-4 shows the data for the new sand. For new sand the AFS specification allows a range of AFS (45-55) and the percentage of fines (1%) max.

Table 5-4: Observations for New Sand with Specification

Date Tested	Pan	AFS	AFS Spec(45-55)	Fines %	Fineness Spec 1% Max
16/01/2015 Cert 01	0	48.32	FALSE	3.17	FALSE
16/01/2015 Cert 04	0	48.78	FALSE	1.06	False
27/01/2015 Cert 07	0	46.77	FALSE	0.61	TRUE

.

5.2.1.3 Green sand properties

Green sand for iron foundries has the following properties as seen in Table 5-5 which is the specification for green sand in foundries. Transnet Foundry uses the specification as shown in Table 5-5.

5.2.1.4 Green sand tests

The green sand specification for tests can be seen in Table 5-5.

Table 5-5: Material properties according to specification

Property	**Jolt/Squeeze machines**	**High Pressure (DISA etc.)**
Water	3-4%	2.5-3.2%
Green strength	70-100kPa (10-15psi)	150-200kPa (22-30psi)
Compactability	45-52%	38-40%
Permeability	80-110	80-100
Live clay	5.0-5.5%	6.0-10%
Volatiles	2.50%	2.00%
LOI	7.0-7-5%	6.00%

The green sand properties for the Foundry for the last six months can be seen in Table 5-6. The portion of the observations as recorded in the Foundry green sand and can be seen in Table 5-6. The rest of the observations can be seen in Appendix 12-3 and Table 12-5 and 200 observations were recorded.

Table 5-6: Green sand properties

Date: Time	**%Moist (2.5%)**	**Compactability (45-52%)**	**Compression Strength**	**Perm (80-110)**	**Green Shear Strength (10-15psi)**
14/01/2015 21H00	3.4	60	6.9	140	5.5
14/01/2015 22H00	3.3	60	6.6	150	5.2
14/01/2015 23H00	3.2	61	6.8	190	5.3
14/01/2015 00H00	3.1	59	6.9	170	5.5

5.2.1.5 Chemically bonded sand

Clean, dry sand is mixed with a binder and a catalyst in a continuous mixer. The mixed sand is vibrated or hand rammed around the mould pattern or into a core box; binder and catalyst react hardening the sand. In all self-hardening processes, the sand quality determines the amount of binder needed to achieve good strength. To reduce additions and therefore cost using high quality sand has the following properties (Brown, 2000):

- AFS 45-60 (Average grain size 250-300 microns.
- Low acid demand value less than 6 ml for acid catalysed systems.
- Rounded grains for low binder additions and flowability.
- Size distribution spread over 3-5 sieves for good packing, low metal penetration and good casting surface.

In the chemically bonded sand section there are three machines that are used for mixing sand data was collected for the 5 ton machine. This can be seen in Table 5-7 and the rest of the data on the other machines can be seen in Appendix 12-4 in Table 12-6 and 62 observations were made.

Table 5-7: Five Ton chemically bonded sand

Date	Shift	AFS	AFS Spec (45-60)	Fines	Fines -Spec (3-5 sieves)
12/01/2015	Day	44.68	FALSE	1.37	FALSE
13/01/2015	Day	43.9	FALSE	1.03	FALSE
15/01/2015	Day	45.42	FALSE	0.88	FALSE

5.2.2 Mould making

In the Transnet Foundry, moulds are made in different areas for green and for chemically bonded sand. Data was collected for the two different areas (green sand and chemically bonded sand to highlight places where resultant moulds were broken and when the hardness of the mould was below specification. Data was collected for the moulds and for the green sand as the hardness of the moulds should always be within specification. In green sand there were no records of broken moulds as the moulding is done by means of a machine.

5.2.2.1 Green sand

The hardness tester was used to measure the hardness of the moulds. The portion of the observation can be seen in Table 5-8. The rest of the observations can be seen in Appendix 12-5 in Table 12-9 and 25 observations were made.

Table 5-8: Green sand data

Green Sand									
			Sample hardness						**Average**
Date	**Type**	**Number of moulds made**	**Specification (80-100)**						
08/05/2015	/17	160	91	87	90	88	86	89	89
	/18	160							
12/05/2015	/17	54	89	87	90	87	89	87	88
	/18	54	88	87	88	85	89	88	
13/05/2015	/17	52	91	88	86	89	87	89	88
	/18	52	88	86	90	88	87	87	88

5.2.2.2 Chemically bonded sand

Moulding in the chemically bonded sand area is a labour intensive process and there are instances when the moulds break. Top centre castings are made from chemically bonded sand. Clean dry sand is mixed with binder and catalyst usually in a continuous mixture. Standard operating procedures indicate there are mixing ratios that should be followed when mixing binder and catalyst. However, the Transnet Foundry does not use them. The artisan doing the mixing uses estimated amounts of resin and catalyst rather than exact measurements. Data on broken and unbroken moulds was collected from the moulds that were made in the different machines (5ton, 10 ton and 25 ton). The sand is hand rammed around the mould pattern into a core box and the binder and catalyst react hardening the sand. Data was collected from the Foundry records for broken moulds from May to September 2015. The portion of data that was collected is contained in Table 5-9 for chemically bonded sand and the balance of the data can be seen in Appendix 12-6 in Table 12-10. The data sheet for moulding can be seen in Appendix 12.6 and 55 observations were made.

Table 5-9: Chemically bonded sand

Chemically bonded sand			
Date	**Casting type**	**Number of moulds made**	**Broken moulds**
07/05/2015	TCC	29	0
08/05/2015	TCC	30	1
11/05/2015	TCC	14	1

5.2.3 Melting

Iron Foundries require metal of controlled composition and temperature supplied at a rate sufficient to match the varying demands of the moulding line. The metallic charge consists usually of foundry returns, iron scrap and pig iron with alloying additions (Brown, 2000). Transnet Foundry uses an induction furnace. In the induction furnace, melting is rapid since high power can be applied. In the Foundry, scrap metal that is used per charge is 8731 kg and the additives are 269 kg whilst the melting furnace is charged with 9 000kg of metal. Of the molten metal that is produced 1000kg gets lost and it becomes slag. Transnet has a contract with NN metals and Sakhubuhlobo and they have to adhere to a specification that is given by Transnet Foundry. The molten metal that is used for brake shoes and top centre castings is the same and the difference is in the mould composition. The charge additions that are added to the molten metal formed from scrap can be seen in Table 5-10.

Table 5-10: Charge additives

Additives			
Material	**Quantity used (Kg)**	**Cost per Kg**	**Cost for amount used**
MC Fe Mn	55	R21.55	R1 185.25
Fe Silicon	78	R17.60	R1 372.80
Al Deox 94%	6	R22.40	R134.40
Flucast	2.8	R7.14	R19.99
Calsif 2-7mm	2.8	R29.32	R82.10
Zincoment L7-20	2.8	R62	R173.60
Mo	16	R236	R3 776.00
Ni	6	R146	R876.00
Bearings	99	R0.26	R25.44
Total (Kg)	**269.00**		
Total for additives	**R7 645.59**		

The data that was collected from the Foundry spectrometer laboratory can be seen in Table 5-11. The melting specification can be seen in Appendix 12.7 in Table 12-11 and 43 observations were made.

Table 5-11: Data from Spectrometer laboratory

Metals		**C**	**Mn**	**Si**	**S**	**P**	**Al**	**Ni**	**Cr**	**Cu**	**Sn**	**Mo**
Temperature	1700											
Specification	**Max**	0.35	1.8	0.6	0.05	0.05	0.06	0.2	0.3	0.4	0.07	N/A
	Min	0.25	1.4	0.4	0	0	0.03	0	0.2	0	0	0.2
	Max	0.28	1.5	0.5	0.04	0.04	0.05	0.15	0.3	0.25	0	0.3
Date												
01/06/2015		0.23	0.82	0.39	0.026	0.025	0.021	0.0081	0.055	0.065	0.013	0.14
02/06/2015		0.23	1.58	0.47	0.032	0.038	0.019	0.008	0.25	0.069	0.015	0.3

5.2.4 Casting

In casting, molten metal is poured into a ladle. The ladle is moved around the casting bay and the molten metal is poured into all the moulds. In casting, moulds are allowed to cool for 30-40 minutes before knocking out the castings. The cooling time not only allows the castings to solidify completely, but it also reduces internal stresses within the casting caused by differential cooling of varying sections. The time it takes to allow for solidification was measured to be 40 minutes although castings are left to cool for even longer periods.

5.2.5 Shake out

The shake-out separates the castings from the sand through the use of a vibrating grid. There is no data that is collected in the shakeout process. Defects such as short cast are visible after the shakeout process, but most defects are not visible at this stage. Fettling, which is the cleaning of castings, has been outsourced and castings only come back when they have been cleaned and are ready for dress to weld.

5.2.6 Dress after Weld

When the castings come back from the external supplier, they are inspected and the go/no/ go gauges are used. When the castings have surface defects that can be seen by a eye, welding is done to ensure that defects are closed. Data has been collected for dress after weld from June, July and August 2015. When dress after weld was done, some of the castings did not gauge and they had to be ground to ensure that they gauge. Data collected from dress to weld can be seen in Table 5-12. This is just a portion of observations and the rest of the data can be seen in Appendix 12.8 in Table 12-12 and 46 observations were made.

Table 5-12: Dress After Weld

Date	Casting type	Total castings	Total Accepted	Do not Gauge
01/07/2015	Brake shoes	72	72	0
02/07/2015	TCC	68	34	2
03/07/2015	Brake shoes	180	180	0
06/07/2015	Brake shoes	200	200	0
07/07/2015	TCC	13	7	0

5.2.7 Heat treatment

Heat treatment is done to ensure that carbides are eliminated in thin sections so as to produce more consistent matrix structures. Mechanical properties are improved by heat treatment especially by normalising. Normalising castings is a form of heat treatment which serves a purpose to remove stresses induced by heat treatment, welding and casting and is done to reduce metal failure in cast iron. Top centre castings are classified as big castings and they are normalised for 12 hours. Brake shoe holders on the other hand are smaller castings and they are normalised for 6 hours. Figure 5-1 shows a heat treatment graph and it indicates that castings have been normalised accordingly. The specification for heat treatment can be seen in Appendix 12-9 in Table 12-13.

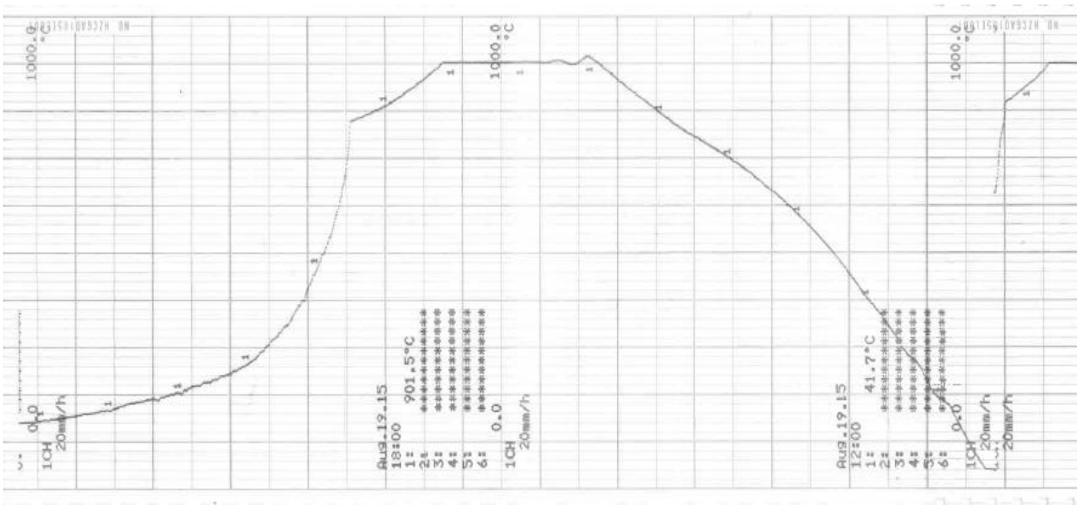


Figure 5-1: Heat treatment curve (Transnet, 2015)

There are three phases involved in normalising castings and they include the ramp up phase. This is when the oven heats up and there is a soaking phase when the temperature in the oven remains constant to ensure that the castings are normalised to an extent that the castings reach a consistent matrix structure. The cooling phase involves allowing the soaking temperature to drop down until the castings cool down.

There are instances when the castings are not normalised well. In this instance, it is imperative that the castings are normalised once more. Reheat is reworking the castings by letting them go through yet another 12 hours of heat treatment. When heat treatment is inadequate the curve that is generated at the end of the cycle shows a straight slanting line and this can be seen in Figure 5-2.

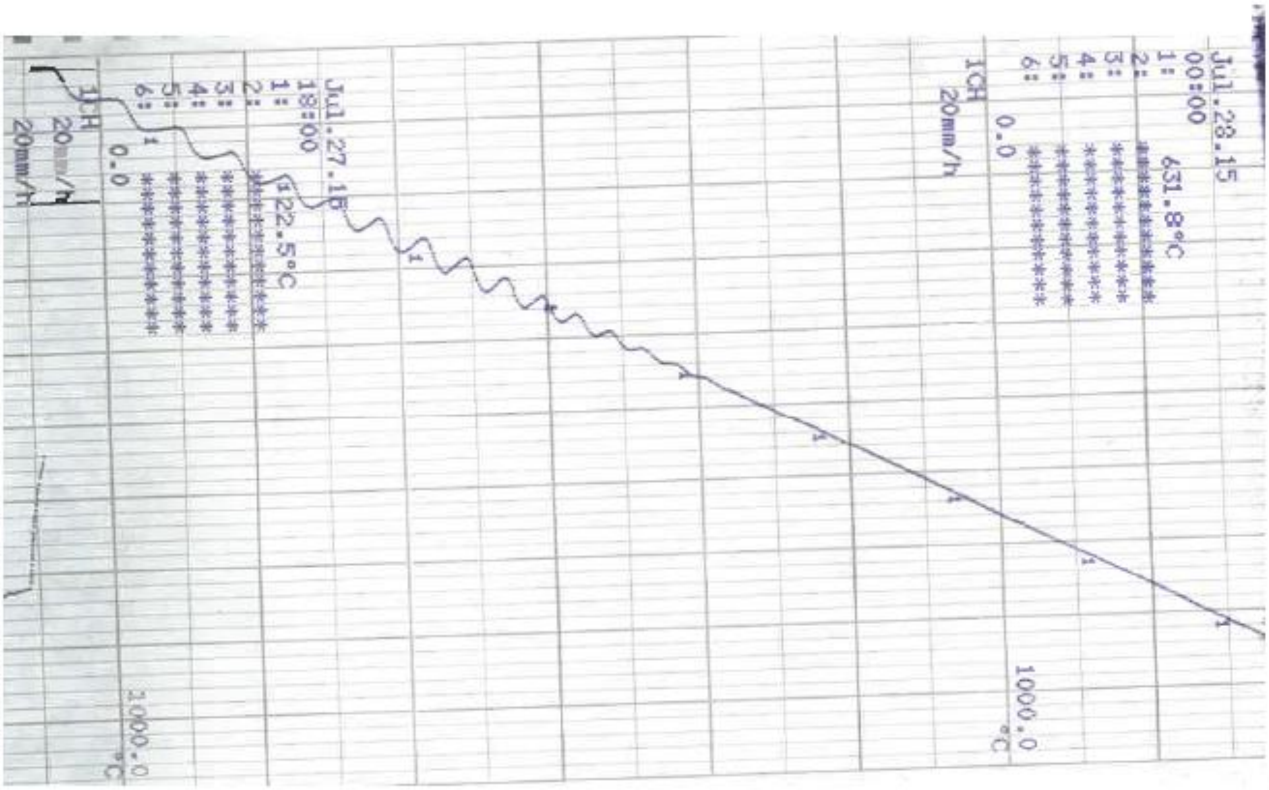


Figure 5-2: Heat treatment curve-Reheat graph (Transnet, 2015)

Data was collected for the heat treatment oven to show what happens during the normalising of castings. Observations were done from June to August. Table 5-13 shows the observations for heat treatment and the temperatures reached on different occasions including instances when reheats had to be done. A portion of Table 5-13 also indicates there are instances when heat treatment is done twice because normalising did not happen accurately. The balance of the data can be seen in Appendix 12-9 in Table 12-13. When the heat treatment curve is not following the correct shape, normalising is re-done and 34 observations were conducted.

Table 5-13: Heat treatment

Spec						
Date	**Ramp up duration(h)**	**Ramp up temperature**	**Soaking duration (h)**	**Soaking temperature (Degrees)**	**Cooling duration (h)**	**Cooling temperature (degrees)**
11/06/2015	2	629.9	3.5	629.9	6	153.5
10/06/2015	Reheat					
12/06/2015	1.5	545	2	545	4	36.1
14/06/2015	2	813	2	813	3.5	0

5.2.8 Casting defects

Casting defects are recorded at the Foundry to investigate which defects occur most often they were recorded over a period of three months from July to September. The results can be shown on Table 5-14. The data was collected from observations conducted in the Foundry and from Table 5-14 it is clear that short casts have the highest number of defects.

Table 5-14: Defects

Defects			
	Quantity		
Type of Defect	**July**	**August**	**September**
Broken mould	9	5	7
Cavities /Porosity	8	6	5
Short Cast	5	10	9
Burst Out	5	6	3
Broken Core	5	4	11
Sand Inclusions	1	1	3
Sand penetration	3	1	1
Shape defect	2	1	3
Dimensional defect	2	5	7
Incorrect Metallurgical composition	1	1	1

5.2.9 Non Compliance Reports

The non-compliance reports recorded in this project were obtained from the results of the internal audit that was held in February 2015. The internal audit was conducted by the personnel from corporate quality. The purpose of the audit at the Foundry was to assess the processes, facilities and technical expertise critical to the quality of the manufactured products. The audit further assured customers that the processes applicable and the technical expertise required for product manufacturing are of a standard that will ensure that the products delivered comply with specified criteria. The audit was conducted based on the principles contained in ISO 9001:2008 with the emphasis placed on verifying the processes ,facilities and technical expertise critical to the product being produced and alignment with the relevant policies, specified requirements and best practise. The resultant findings from the audit report can be seen in Table 5-15.

Table 5-15: Audit Findings

Date of Audit	Type of Audit	ISO 9001:2008	Responsibility	Findings
24/02/2015	Internal	ISO 9001:2008	Corporate Quality	No quality controllers on the workshop floor.
24/02/2015	Internal	ISO 9001:2008	Corporate Quality	Furnace gauges out of calibration.
24/02/2015	Internal	ISO 9001:2008	Corporate Quality	Tap measurements are not recorded on the check sheet provided.
24/02/2015	Internal	ISO 9001:2008	Corporate Quality	Quality control documents are not kept in a central place.
24/02/2015	Internal	ISO 9001:2008	Corporate Quality	High scrap rate was observed on the top centre casting.
24/02/2015	Internal	ISO 9001:2008	Corporate Quality	No tolerance range for moisture and shear on the green sand check sheet.

24/02/2015	Internal	ISO 9001:2015	Corporate Quality	Pattern storage is not access controlled and housekeeping is a problem and as a result mould patterns were found damaged
24/02/2015	Internal	ISO 9001:2008	Corporate Quality	Pattern register must be developed and the issuing of patterns must be monitored and controlled for quality purposes
24/02/2015	Internal	ISO 9001:2008	Corporate Quality	Audit team did not witness the fettling process as there was no production taking place

Non Compliance Reports (NCR) are issued mainly because certain processes and procedures have not been done correctly. Transnet Foundry issued NCRs from July to October mainly for the reasons that have been stated in table 5-16. The total number of NCR’s received from July to September is 64.

Table 5-16: Reasons for NCRS issued

Reasons For Issuing NCRS			
	Quantity		
Type of Defect	**July**	**August**	**September**
Not complying to spec	1	2	3
Sand Preparation	1	1	1
No heat treatment	1	4	3
Cutting	1	3	2
Dressing	1	2	3
Incorrectly machined	1	1	1
Product not conforming to spec requirements	5	3	1
Incorrectly fettled	4	3	2
Sand penetration	3	1	1
Incorrect Metallurgical composition	1	1	1
Delivered product damaged	1	2	3
Total	**20**	**23**	**21**

5.3 Summary of data collection

Data was collected for all the processes in the casting of top centre castings and in the casting of brake shoe holders. The data indicates there are some inconsistencies with adherence to the specifications and as a result the processes in some areas are not adequately followed. Data will be analysed to check the improvements that can be done for the Transnet Foundry.

6. PHASE 3 ANALYSIS - DATA ANALYSIS

This chapter will cover the analysis of the data that was collected in the previous chapter. The data analysis will address the propositions which include the quality issues in the Foundry as determined by the collected data. The analysis will give an indication of the cost of quality in the Foundry business. The impact of quality defects on the productivity in the business will be quantified.

6.1 Sand Preparation

Return sand

Fine grained sands yield a better surface finish, but they need higher binder content and the low permeability may cause gas defects in castings. The specification indicates that fines content should be below 2% maximum for return sand. A pie chart in Figure 6-1 indicates the sample of data collected in Table 5-3. Analysis involved counting the instances in Table 5-3 when the sand Fines complied with specification. Results indicated that 64% of the time the fines content was not within specification and only 36% of the time was the specification met.

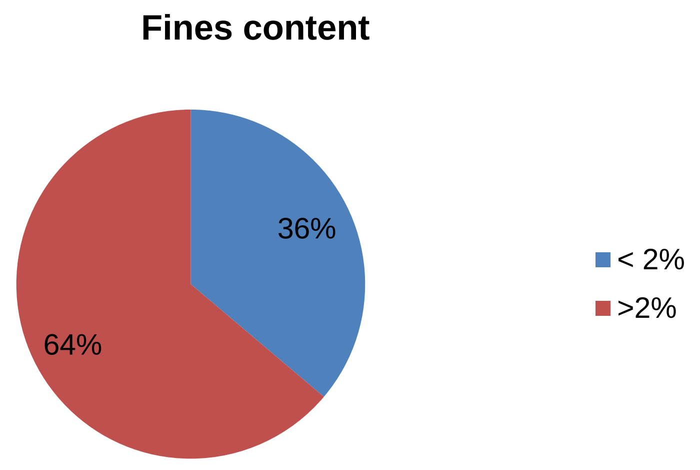


Figure 6-1: Fines compliance to specification for return sand

Another property of sand that requires analysis is the grain fineness number abbreviated (AFS).The purpose of the AFS test is to determine how resistant it is to squeeze and the compaction of the loose sand. Grain fineness refers to a measure of the average size of the grains in sand. The specification indicates that for the Foundry grain fineness within the range (45-60) AFS should be achieved. The (45-60) AFS yields a good surface finish at low binder levels. Analysis involved counting the instances when the AFS complied with specification. The results indicate that the Foundry produced castings with sand that did not conform to specification 75% of the time that production was monitored. This can be illustrated by the pie chart as seen in Figure 6-2. The pie chart shows that only 25% of the data complies with specification.

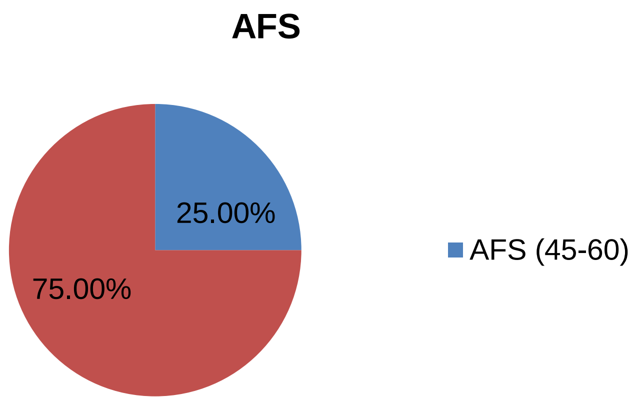


Figure 6-2: AFS compliance to specification for return sand

New sand

The specification for new sand has an AFS ranging (45-55) and the fines are supposed to be below 1.0% maximum. New sand is purchased from external suppliers and it is expected to comply to the specification. Data collected indicated that the new sand that gets tested conforms to the specification 35% of the time and in 65% of the instances it does not comply to specification. This is charted in Figure 6-3. The analysis was done by counting the number of the observations in which sand complied with specification.

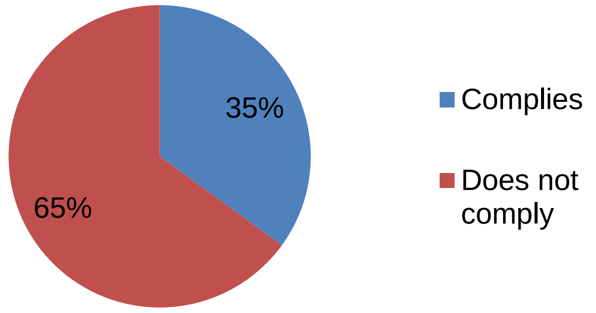


Figure 6-3: AFS Compliance to specification for new sand

The specification for the fines is supposed to be below 1.0% maximum. Figure 6-4 indicates that 29% of the time the new sand complies with specification and for 71% it does not comply with specification. This leaves room for defects to occur, especially in sand preparation.

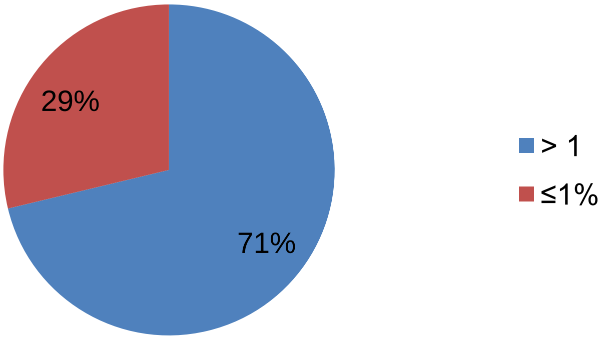
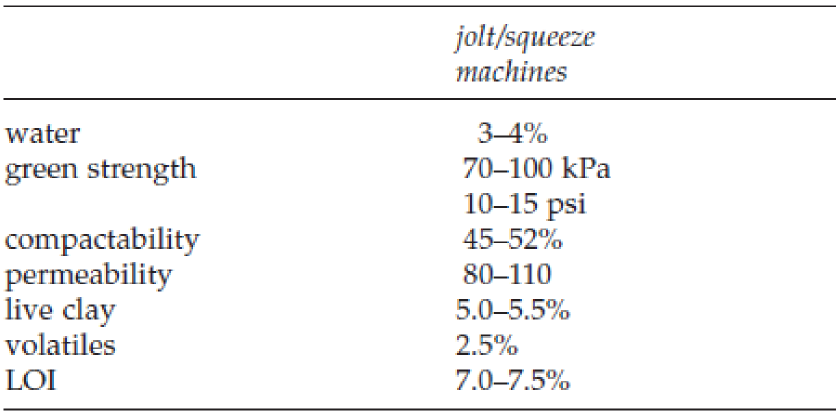


Figure 6-4: Fines Compliance to specification for new sand

Green sand properties

Regular testing of the properties of sand is essential and one or two sand tests do not truly indicate the condition of the whole sand system since a sample weighs 1kg and the full load may be up to 200 tonnes. The Foundry practise requires at least five samples to be taken per shift and measured for moisture, green strength, compactability and permeability. Loss of ignition and volatiles can be measured once per day.

Green sand for iron foundries has the following specification as shown in Figure 6-5.



	jolt/squeeze machines
water	3–4%
green strength	70–100 kPa 10–15 psi
compactability	45–52%
permeability	80–110
live clay	5.0–5.5%
volatiles	2.5%
LOI	7.0–7.5%

Figure 6-5: Green sand properties (Brown, 2000)

Ideally an iron Foundry should measure the green sand properties such as water, green strength, compactability, permeability, live clay, volatiles and LOI. The Transnet Foundry only measures moisture, compactability, compression strength, permeability and green shear strength. Table 6-1 indicates the green sand properties that are measured at the Foundry and the values are an average of the data that was collected over a period of six months. The data was obtained from the sand laboratory records as recorded in Appendix 12.3 in Table 12-5. Table 6-1 also allows for a comparison between the specification and the actual readings of what is happening in the plant. On average the green sand's moisture in the Foundry is within specification and compactability is outside of specification. Permeability and green shear strength do not meet specification.

Table 6-1: Green sand properties

Properties	Specification	Actual Average
Moisture	(3-4%)	3.18
Compactability	(45-52%)	54.5
Compression strength	10.34 kPa	7.48
Permeability	(80-110)	174
Green shear strength	(10-15psi)	5.8

When iron or steel is poured into green sand moulds, the heat from the metal drives off some water from the sand and clay burns some of the coal dust to coke and ash, and burns a proportion of the clay so that its bonding properties are destroyed. It is imperative that 10% of new silica sand is added to the system and to dispose of corresponding amount of used system sand (Brown, 2000). However this is not currently done at the Transnet Foundry which negatively affects the quality of the return green sand and this consequently affects castings produced.

Chemically bonded sand

In all self-hardening processes, the sand quality determines the amount of binder needed to achieve good strength. To reduce additions and cost, high quality sand is used. In the chemically bonded sand section, there are three machines in which moulding can be done. These include the 5, 10 and 25 ton machines. The recorded data for moulding sand on all the machines was analysed to check if the results comply with the specification of AFS (45-60) and size distribution of 3-5 sieves for good packing, low metal penetration and a good casting surface. The analysis was done by counting the instances when the AFS in each machine complied to specification and was marked as true and the instances when AFS did not comply was marked as false. These were then counted and the percentage that were were out of specification was recorded and summarised as shown in Table 6-2 to table 6-4. The balance of the data can be seen in Appendix 12.12 in Table 12-29.

Table 6-2: Frequency of AFS when in specification for 10 Ton Machine

AFS 10 Ton		
True	21	41.18%
False	30	58.82%
Observations	51	

The percentage frequency for the 5 ton and 25 ton when the AFS was out of specification can be seen in Table 6-3 and Table 6-4.

Table 6-3: Frequency of AFS when in specification for 25 Ton

AFS 25 Ton		
False	40	50%
TRUE	40	50%
Observations	80	

Table 6-4: Frequency of AFS when in specification for 5 Ton

AFS 5 Ton		
TRUE	5	8.06%
FALSE	57	91.94%
Observations	62	

The summary of instances when AFS was out of specification for all three machines can be seen in Table 6-5.

Table 6-5: Comparison in Chemically bonded sand

Machine	**Out of specification**	**AFS (45-60)**	**Fines (3-5)**
5 Ton	91%	42	1.46
10 Ton	58%	47	5
25 Ton	50%	44	3

The actual readings from the collected results show a large variation and the process is not stable. To illustrate the large variations statistical process control charts were drawn as shown in Figure 6-5 to Figure 6-10. The AFS numbers fluctuate over the different observations and this has an impact on the castings that are produced on different days. For the chemically bonded sand machines (5 ton, 10 ton and 25 ton) the control charts were drawn.

The data table can be seen in Appendix 12.12 in Table 13-28.The formulas for setting up the Statistical Process Control (SPC) chart can be seen below can be seen in Table 6-6.

AFS and Fines control charts calculations for 5, 10 and 20 ton machines

The AFS data for the three different machines in the chemically bonded sand was analysed using the statistical process control charts. The statistical analysis was done for all three machines and the results can be seen in Figure 6-5 to 6-10.

AFS Control chart calculation for 5, 10 and 25 ton machine can be seen in Table 6-6.

Table 6-6: Calculation for control charts

	AFS 5 Ton	**AFS 10 Ton**	**AFS 25**	**Fines 5 Ton**	**Fines 10 Ton**	**Fines 25 Ton**
Mean	41.73	46.85	43.64	1.13	5.27	1.88
Maximum	46.29	71.05	54.35	4.19	17.85	6.55
Minimum	37.55	33	33.73	0.11	0.14	0.17
Range	8.74	38.05	20.62	4.08	17.71	6.38
standard deviation (SD)	2.30	8.41	4.11	0.87	4.72	1.77
n	51					
Assume alpha is 5% which means that Z = 1.96	1.96					
UCL = Mean +Z*(SD/sqrt(n))	42.37	49.16	44.77	1.37	6.56	2.36
LCL = Mean -Z*(SD/sqrt(n))	41.10	44.55	42.51	0.89	3.97	1.39
USL	60	60	60	5	5	5
LSL	45	45	45	3	3	3

AFS 5 Ton Machine

The control chart for the 5 ton machine was drawn as shown in Figure 6-6.

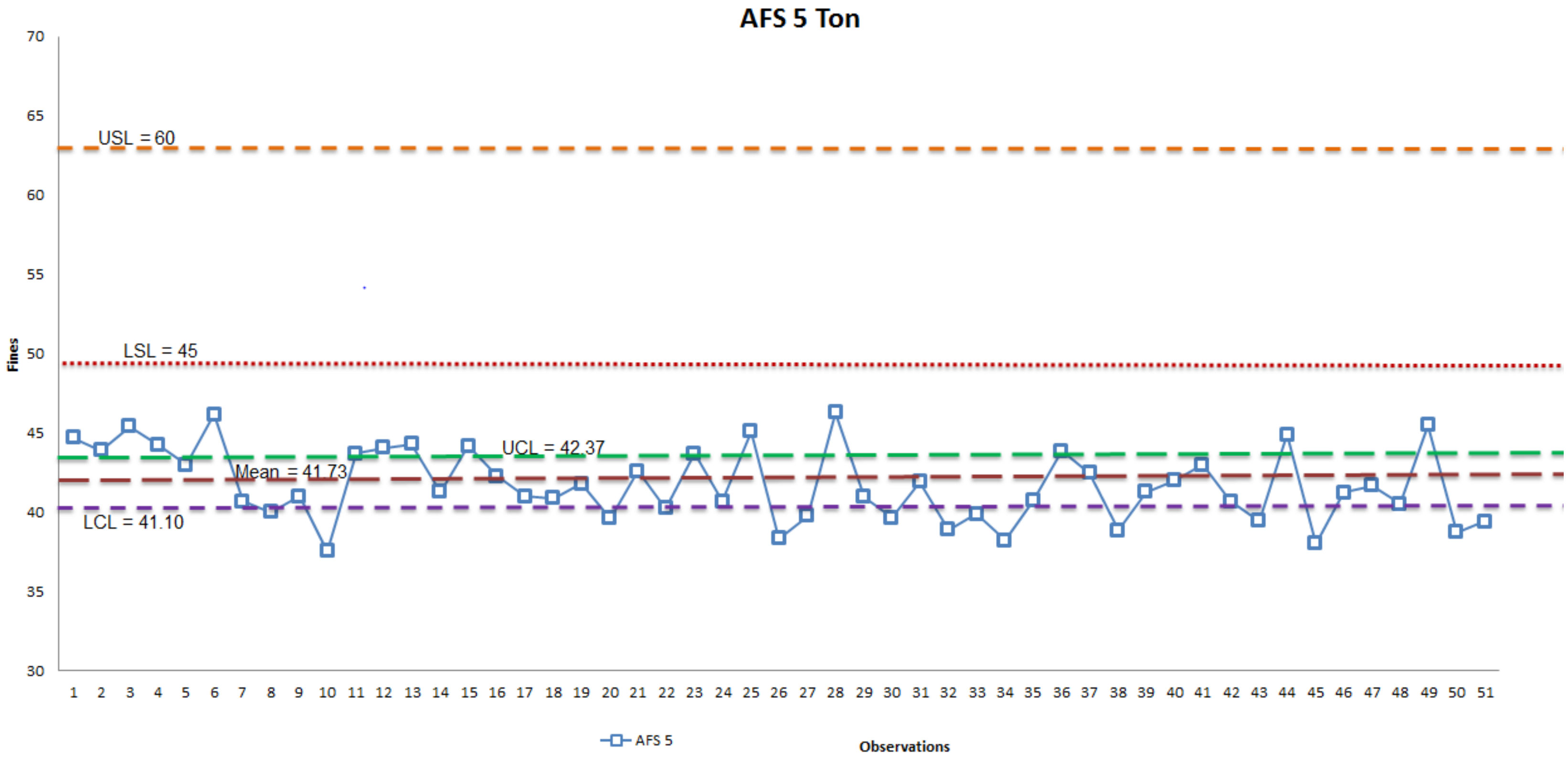


Figure 6-6: Control Chart for AFS 5 Ton

The control chart indicates that the process has shifted below the lower and upper specification limit. Moreover, the process is out of control as most of the data points are outside the control limits.

AFS 10 Ton Machine

The control chart for the 10 ton machine can be shown below in Figure 6-7.

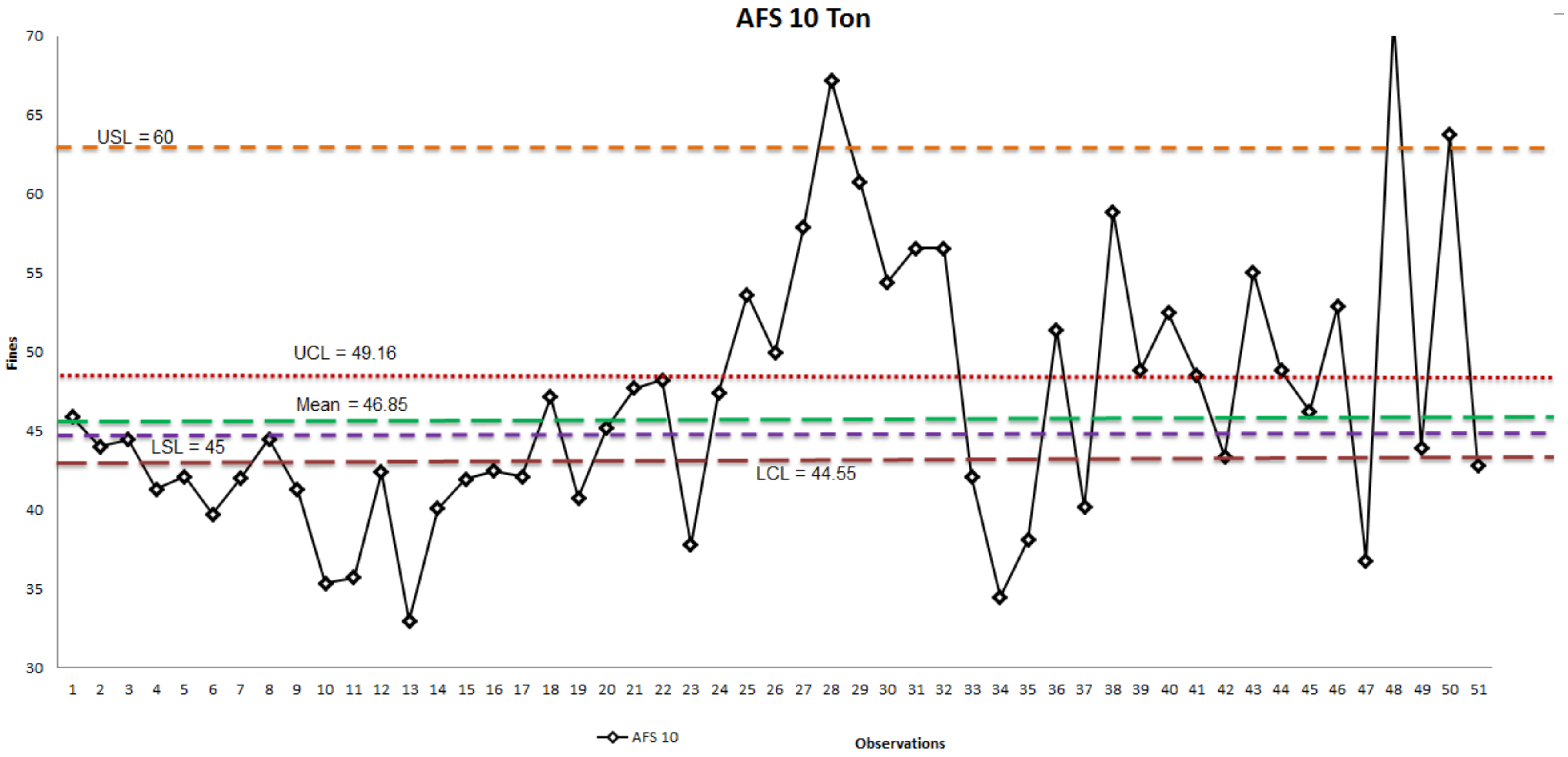


Figure 6-7: Control Chart for AFS 10 Ton

The control chart indicates that the process is out of control as data points fall outside of both the control limits and the specification limits. There is also high variability in the process as indicated by the standard deviation of 8.41 and the range of 38.05 which are approximately 3.5 times and twice as high, respectively, in comparison with the other two machines.

AFS 25 Ton Machine

The control chart for the 25 Ton machine can be seen in Figure 6-8.

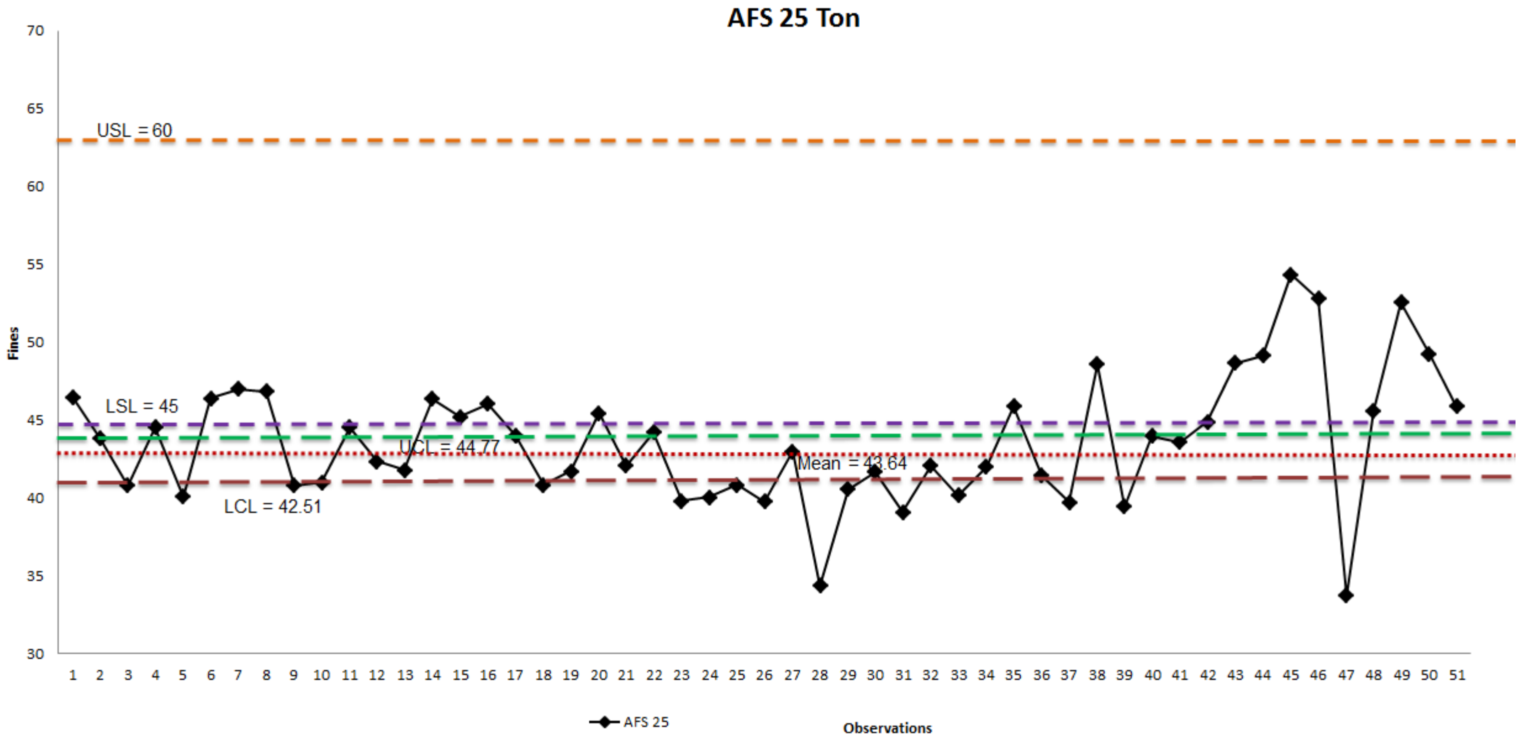


Figure 6-8: Control Chart for AFS 25 Ton

The control chart has shifted down and most of the points are outside the lower and upper specification limits. This process is not in control.

Control chart for Fines for the 5 Ton Machine

The control chart for the Fines for the 5 ton machine can be seen in Figure 6-9.

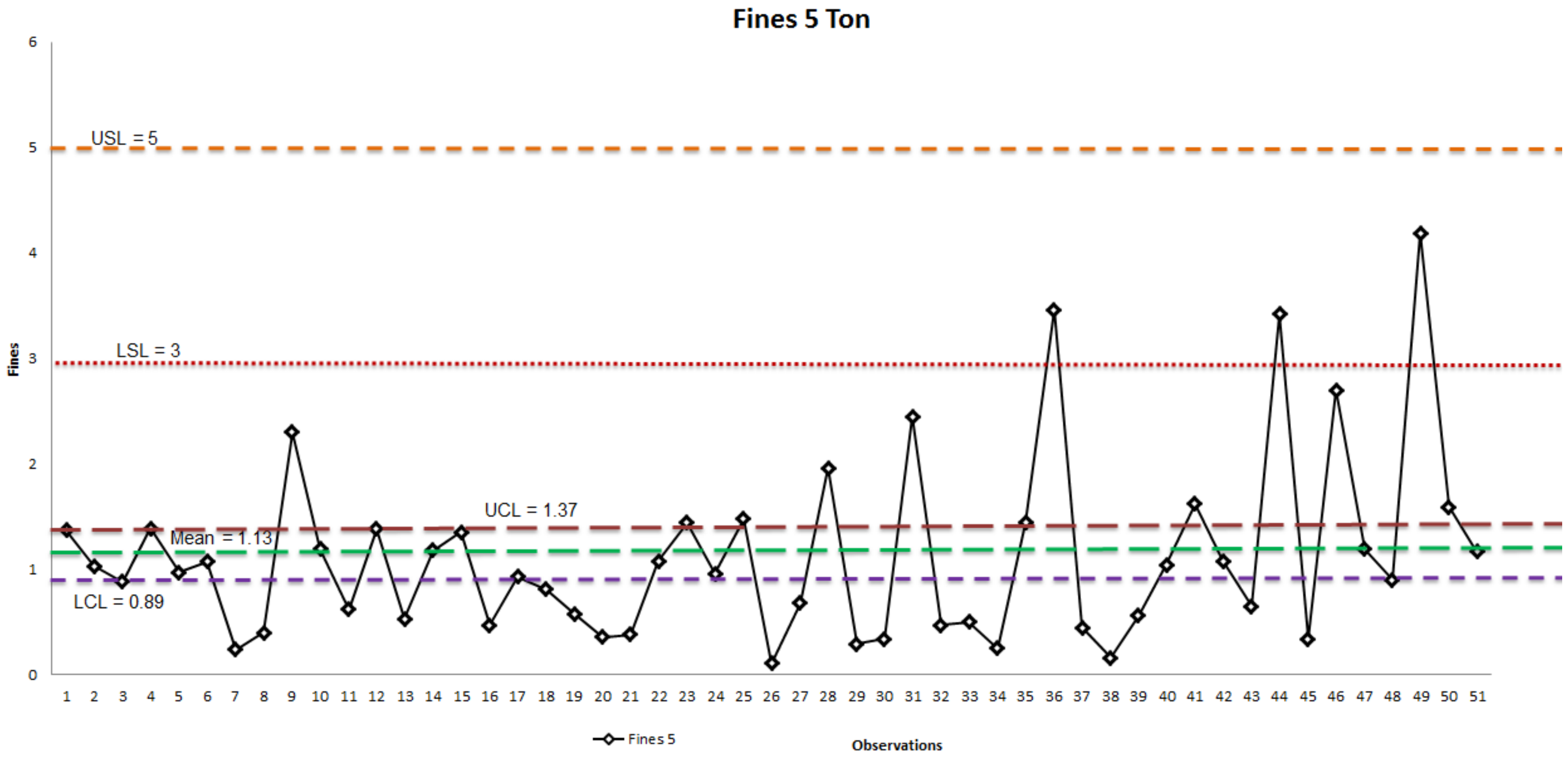


Figure 6-9: Control chart for Fines 5 Ton

Observations indicate there is a lot of variation on the fines in the control chart and the process is out of control.

Fines 10 Ton Machine

The control chart for the fines for the 10 Ton machine can be shown below in Figure 6-10.

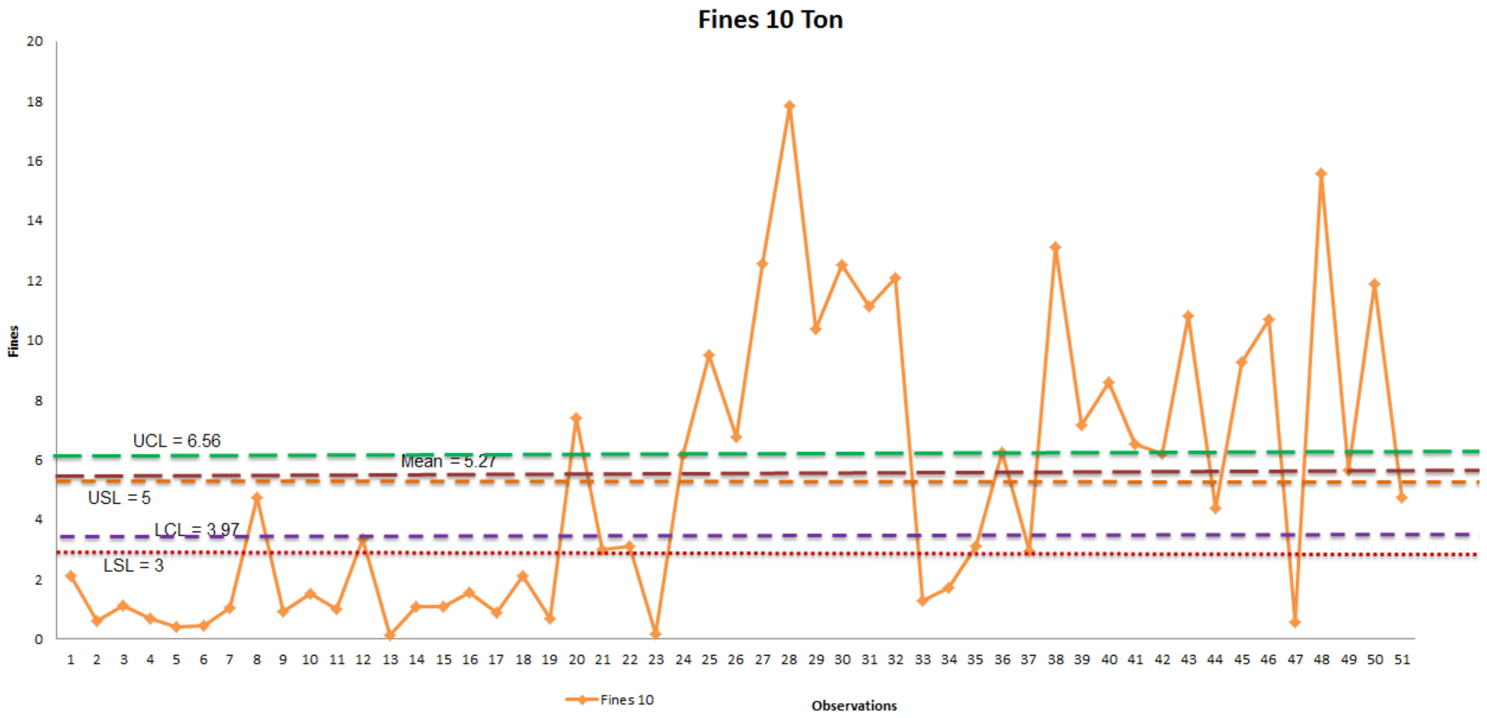


Figure 6-10: Control Chart for Fines 10 Ton

The process is out of control and there are many points that are outside the control limits. There is also high variability when the standard deviation and the range are compared with the other two machines.

Fines 25 Ton

The control chart for the Fines for the 25 ton machine can be seen in Figure 6-11.

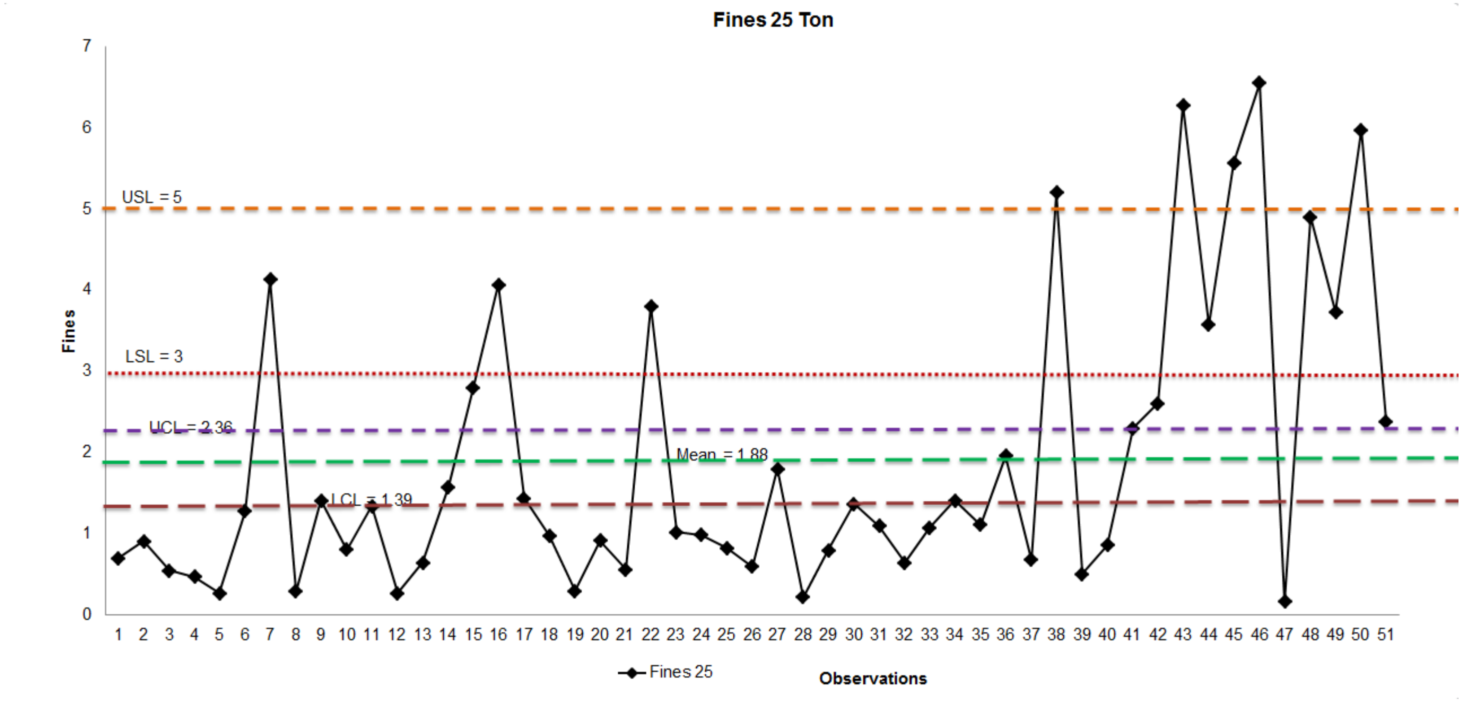


Figure 6-11: Control Chart for Fines 25 Ton

The process is out of control and the data points are outside the specification limits.

Process Capability

Process capability is the ability of a process to meet design specifications which are set by engineering design or customer requirements **(Heizer & Render, 2014)**. Even though the process may be statistically in control, the output of that process may not conform to specifications **(Heizer & Render, 2014)**. A Cp of less than 1 indicates that the process is not capable. The three machines will be analysed to check if they are capable.

AFS Machines Process Capability

$$\mathrm{C_{pk}} = \frac{\mathrm{USL} - \mathrm{LSL}}{6\sigma}$$

$\mu_{5\ ton}$ =41.73

$\mu_{10\ ton} =$ 46.85

$\mu_{25\ ton} =$ 43.64

Standard deviation for 5 Ton Machine

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2}$$

$$\sigma = \sqrt{\frac{1}{51}\sum(44.68 - 41.73)^2 + (43.9 - 41.73)^2 + \cdots \ldots..(39.43 - 41.73)\text{\textasciicircum}2}$$

σ = 2.75

$$\mathrm{C_{pk}} = \frac{\mathrm{USL} - \mathrm{LSL}}{6\sigma}$$

$$\mathrm{C_{pk}} = \frac{60 - 45}{6 * 2.75}$$

$$\mathrm{C_{pk}} = \frac{15}{16.5}$$

$$\mathrm{C_{pk}} = 0.9$$

This means that the machine is not capable of producing the correct quality of sand.

Standard deviation for 10 Ton Machine

$$\sigma = \sqrt{\frac{1}{51}\sum (45.89-46.85)^2 + (44.02-46.85)^2 + \cdots \ldots\ldots (42.78-46.85)\char`^2}$$

σ = 8.32

$$\mathrm{C_{pk}} = \frac{\mathrm{USL}-\mathrm{LSL}}{6\sigma}$$

$$\mathrm{C_{pk}} = \frac{60-45}{6*8.32}$$

$$\mathrm{C_{pk}} = \frac{15}{49.92}$$

$$\mathrm{C_{pk}} = 0.3$$

The process capability is less than 1 therefore the machine is not capable.

Standard deviation for 25 Ton Machine

$$\sigma = \sqrt{\frac{1}{51}\sum (46.49-43.64)^2 + (43.86-43.64)^2 + \cdots \ldots\ldots (45.88-43.64)\char`^2}$$

σ = 4.07

$$\mathrm{C_{pk}} = \frac{\mathrm{USL}-\mathrm{LSL}}{6\sigma}$$

$$\mathrm{C_{pk}} = \frac{60-45}{6*4.07}$$

$$\mathrm{C_{pk}} = \frac{15}{24.42}$$

$$\mathrm{C_{pk}} = 0.61$$

The process capability is less than one and this means that the machine is not capable of producing products that comply with specification. The capabilities calculated for all three machines indicate that the machines are not capable of producing in line with the customer requirements.

6.2 Mould Making

Green sand

The moulding machine must compact the green sand evenly around the mould pattern to give the mould sufficient strength to resist erosion while liquid metal is poured. The sample hardness is measured on a daily basis each time green sand moulding is done for the tenth mould. To analyse the sample hardness for the month of May to September, an average was taken for the sample hardness for data collected. The balance of the data can be seen in Appendix 12-14 in Table 12-30 and a control chart shown in Figure 6-11 was drawn. Table 6-7 indicates the hardness of the green sand moulds. There are no records of broken moulds. The calculations for the control limits can be seen in Table 6-7.

Table 6-7: Control limits with alpha of 5%

Green sand (Brake Shoe holder)	**Sample hardness**
Mean	88.33
Maximum	89.00
Minimum	87.50
Range	1.50
standard deviation (SD)	0.36
n	48
Assume alpha is 5% which means that Z = 1.96	1.96
UCL = Mean +Z*(SD/sqrt(n))	88.44
LCL = Mean -Z*(SD/sqrt(n))	88.23
USL	100
LSL	80

The control chart was ploted as shown in Figure 6-12.

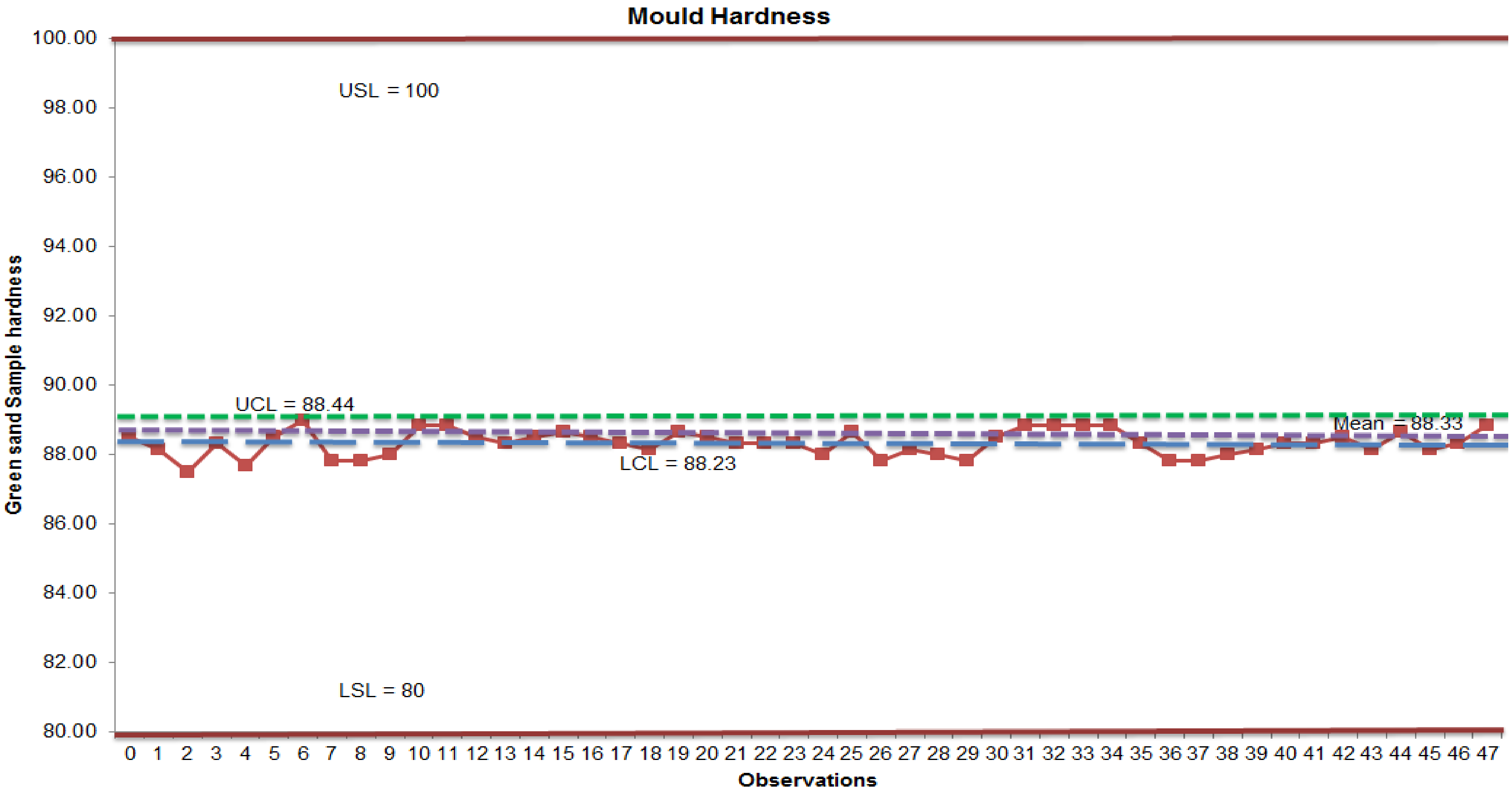


Figure 6-12: Sample hardness of green sand moulds

There are a significant number of points that fall above the UCL in Figure 6-12 which means that the process is not in control. A capability study will be conducted as shown below:

$$\sigma = \sqrt{\frac{1}{48}\sum(89-88.37)^2+(88-88.37)^2+\cdots\ldots..(89-88.37)\text{^}2}$$

σ = 0.13

$$\mathrm{C_p} = \frac{\mathrm{USL}-\mathrm{LSL}}{6\sigma}$$

$$\mathrm{C_p} = \frac{100-80}{6*0.13}$$

$$\mathrm{C_p} = \frac{20}{0.78}$$

$$\mathrm{C_p} = 25.64$$

Calculations indicate that Cp has a value greater than one however observations indicate the process is out of control. Recalculations were done with alpha of 10% and the results can be seen in Table 6-8.

Table 6-8: Control limits with alpha 10%

Green sand (Brake Shoe holder)	**Sample hardness**
Mean	88.33
Maximum	89.00
Minimum	87.50
Range	1.50
standard deviation (SD)	0.36
n	48
Assume alpha is 10% which means that Z = 1.645	1.645
UCL = Mean +Z*(SD/sqrt(n))	88.42
LCL = Mean -Z*(SD/sqrt(n))	88.25
USL	100
LSL	80

Table 6-8 shows that there is no significant change in the UCL and LCL values when an alpha of 10% is used to calculate the control limits.

Chemically bonded sand

In the chemically bonded sand section, the sand is hand rammed around the pattern and the binder and catalyst react in order to harden the sand. In the chemically bonded sand section, moulds break. The moulds that were recorded as broken are those that could not be reworked. Figure 6-13 shows the number of moulds that were made and the number of moulds that were broken and could not be repaired. The percentage of broken moulds is also shown on Figure 6-13.

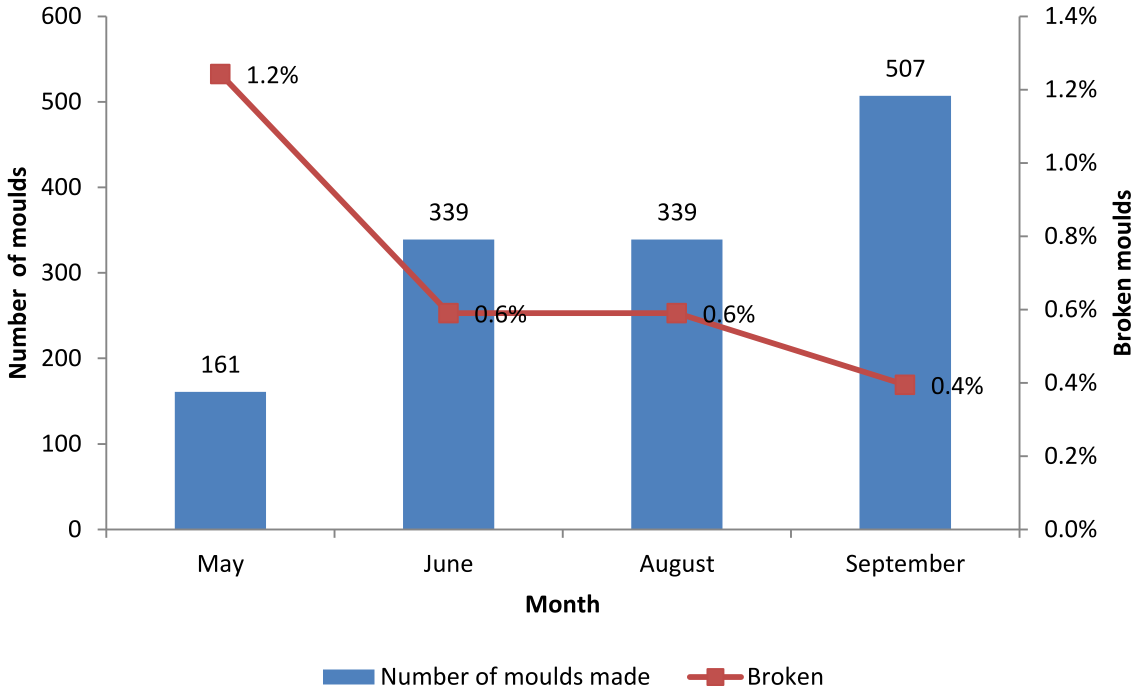


Figure 6-13: Broken moulds

The mould has an impact also on the size precision of the final casting. If the mould is not dimensionally accurate, the actual casting will reflect this. Precise casting moulds enable the Foundry to get casting parts with precise sizes. Good quality moulds should also help in achieving a smooth surface finish for the actual casting. When a liquid metal is cast into sand or against a core, there may be physical effects and a chemical reaction at the sand/metal interface may occur .This may result in surface defects on the finished casting. As a result, there is a need for a coating for moulds.

6.3 Melting

The melting department has a specification that they work with in order to produce quality molten metal. Data was collected from the Foundry business records. Data was collected over a period of 3 months from June to August 2015. Defects that occur in melting are mainly caused by de-oxidation. This happens when liquid steel dissolves in oxygen as the steel cools and dissolved oxygen combines with carbon in the steel, forming carbon monoxide. This happens during solidification. In carbon steels 0.06% of sulphur may be tolerated.

Careful selection of charge materials is necessary to ensure low sulphur in induction melted steels. Inclusion defects in steel castings can arise from slag entrapment, or from the erosion of the furnace or ladle linings and refractories. Gas porosity defects in melt are formed due to hydrogen and carbon monoxide. To minimise porosity, the hydrogen and nitrogen contents of the liquid must be minimised and the carbon oxygen reaction prevented by a sufficiently strong de-oxidation practise. Hot tearing defects are commonly caused by the contraction of the steel which on freezing is hindered by the mould or cores.

To analyse the data, the average in chemical compositions for the different metals was taken and for example for carbon, the average was computed for all the readings that were observed. A graph was drawn to check for variations in the molten metal composition which concurrently affect the castings produced. Table 6-9 shows the specification for the different metals that are tested in the molten metal and the observations data.

Table 6-9: Molten Metal Specification and observations

Specification	**Metals**	**C**	**Mn**	**Si**	**S**	**P**	**Al**	**Ni**	**Cr**	**Cu**	**Sn**	**Mo**
	Temperature											
	Max	0.35	1.8	0.6	0.05	0.05	0.06	0.2	0.3	0.4	0.07	N/A
	Min	0.25	1.4	0.4	0	0	0.03	0	0.2	0	0	0.2
	Max	0.28	1.5	0.5	0.04	0.04	0.05	0.15	0.3	0.25	0	0.3
Observations	**Chemical composition**	**C**	**Mn**	**Si**	**S**	**P**	**Al**	**Ni**	**Cr**	**Cu**	**Sn**	Mo
	Max	0.32	1.75	0.60	0.04	0.06	0.08	0.09	0.30	0.08	0.07	0.34
	Min	0.16	0.69	0.31	0.01	0.00	0.00	0.01	0.03	0.03	0.00	0.01
	Average Readings	0.25	1.02	0.40	0.02	0.03	0.03	0.02	0.14	0.05	0.01	0.19

Table 6-9 shows that for element Carbon abbreviated C, the specification requires a maximum value of 0.35 and on observations from the spectrometer laboratory, the maximum for carbon was 0.32 and the minimum according to specification is 0.25 however, the records showed 0.16. This shows that the composition of metals in the molten metal do not always conform to specification. Figure 6-14 shows that the metals used do comply with specification although there can be differences.

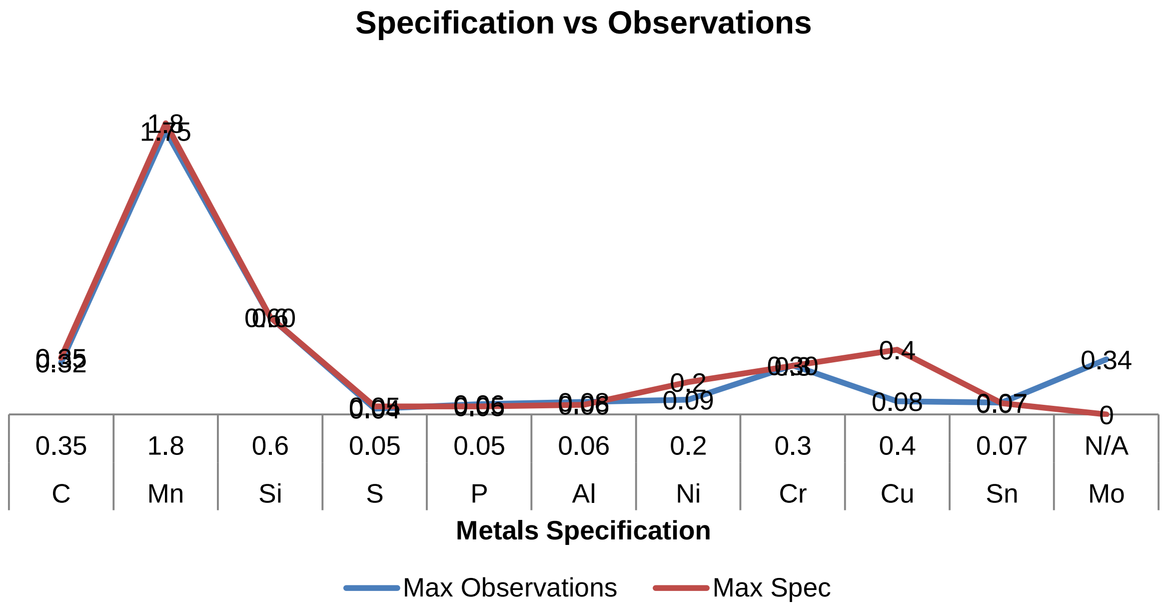


Figure 6-14: Composition of molten metal

6.4 Casting

The Foundry does not conduct any form of time studies when casting is done. Precautions are taken when the molten metal is prepared. When casting, careful attention should be taken to ensure that slag is prevented from entering the mould. The running and gating systems encourages thermal gradients within the casting which in turn help to produce sound castings.

Filters were originally introduced in casting to prevent non-metallic inclusions in the liquid metal from entering the casting and it is imperative that the Transnet Foundry also adopts filters which are currently not in use. Inclusions in casting can occur outside the mould and they are mostly caused by melting furnace slag, oxidation products and contaminants. These are foreign objects. Some inclusions are generated inside the mould and are mostly as a result of loose sand, mould and core erosion.

6.5 Dress after Weld

Fettling of the castings has been outsourced and this involves shot blasting, cutting, dress to gauge and machining. The castings only come back to the Foundry for final inspection and they are welded if there are surface defects. The study focused on the brake shoes and top centre castings. The sample of data collected had 7434 brake shoe holders and 236 top centre castings received from the suppliers . This can be seen in Table 6-9.

Table 6-10: Quantities of castings in Dress after Weld

Casting type	**Total castings**	**Total accepted**	**Do not gauge**	**Rework**	**Accepted**	**Do not gauge**	**Rework**
Brake shoes	7434	5893	1094	447	79%	15%	6%
TCC	236	196	2	38	83%	1%	16%

The castings that have defects as shown by the picture in Figure 6-15 need to be welded.

Figure 6-15: Castings after dress after Weld

Data was collected for brake shoe holders and top centre castings and the results indicated that there are many more brake shoe holders that are cast in a day than top centre castings. Figure 6-16 show the number of brake shoe holders that were dressed after welding from June to August 2015. When an inspection was done, 79% of the castings were accepted and 15% did not gauge and only 6% was reworked. Castings that do not gauge are ground accordingly until they gauge.

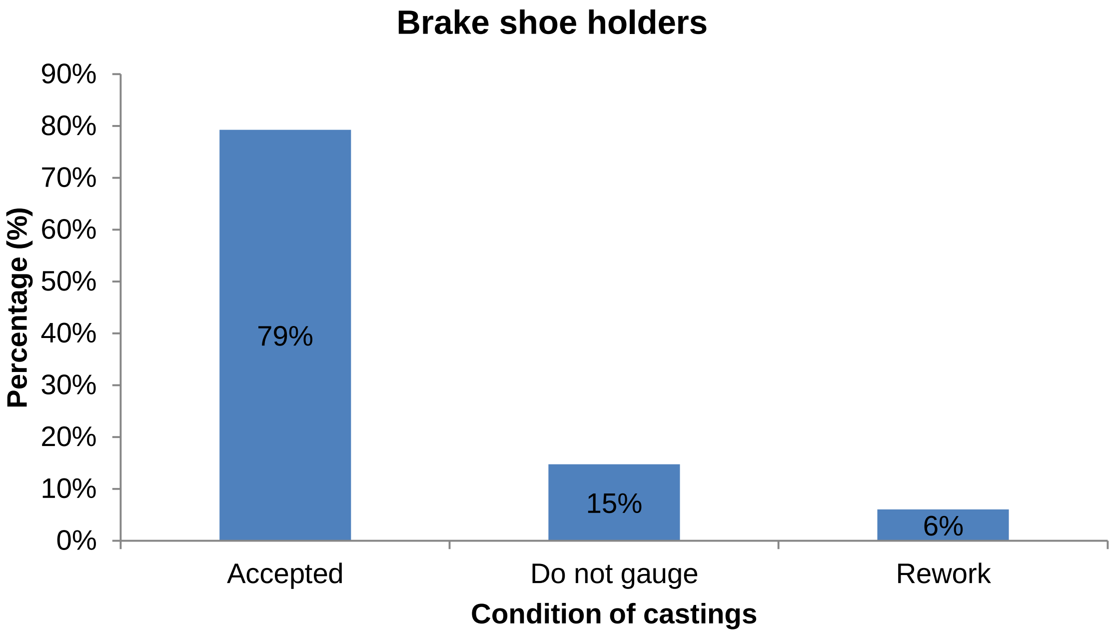


Figure 6-16: Brake shoes after inspection

For top centre castings, a low number of castings were manufactured for the period of June to August 2015. Top centre castings are much bigger castings. Figure 6-17 shows the 83% of the top centre castings passed inspection with a 16% re-work and 1% of the castings did not gauge.

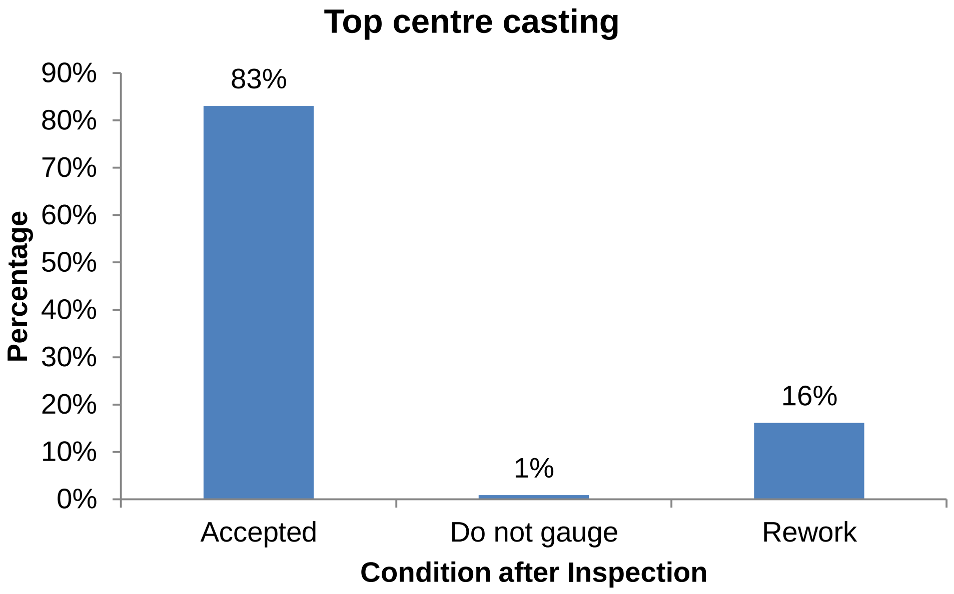


Figure 6-17: Top centre casting after dress after weld

6.6 Heat treatment

Heat treatment of the castings is done to eliminate the carbides in thin sections in order to produce more consistent matrix structure. The mechanical properties are often improved by heat treatment especially normalising. For the castings at Foundry, tempered martensite is needed and as a result heat treatment is done. Castings need to be soaked above the critical temperature then air cooled. Soaking temperature of (900-925) degrees Celsius eliminates carbides and forced air cool enables a pearlite structure to be formed. At Transnet Foundry heat treatment is done and data is collected to monitor if the castings are normalised at the specified temperatures. Figure 6-18 shows there are instances when the soaking temperature does not reach the specified range (900-925) degrees Celsius and this may have an impact on the defects that may be discovered further in the process especially with regards to the strength of castings. The calculations for the control limits can be seen in Table 6-11.

Table 6-11: Heat treatment control chart

Heat treatment	
Mean	807.25
Maximum	960.00
Minimum	545.00
Range	415.00
standard deviation (SD)	103.22
n	24
Assume alpha is 5% which means that Z = 1.96	1.96
UCL = Mean +Z*(SD/sqrt(n))	848.54
LCL = Mean -Z*(SD/sqrt(n))	765.95
USL	925
LSL	900

The control chart was plotted in Figure 6-17 and it shows that the process was out of control.

$$\sigma = \sqrt{\frac{1}{24}\sum(629.9-807)^2+(545-807)^2+\cdots\ldots..(796-807)\text{^}2}$$

$$\sigma = 10210$$

$$\mathrm{C_p} = \frac{925-900}{6 * 10210}$$

$$\mathrm{C_p} = 0.000401$$

Cp is less than 1 and this means that the heat treatment process is not capable of producing castings that have improved mechanical properties.

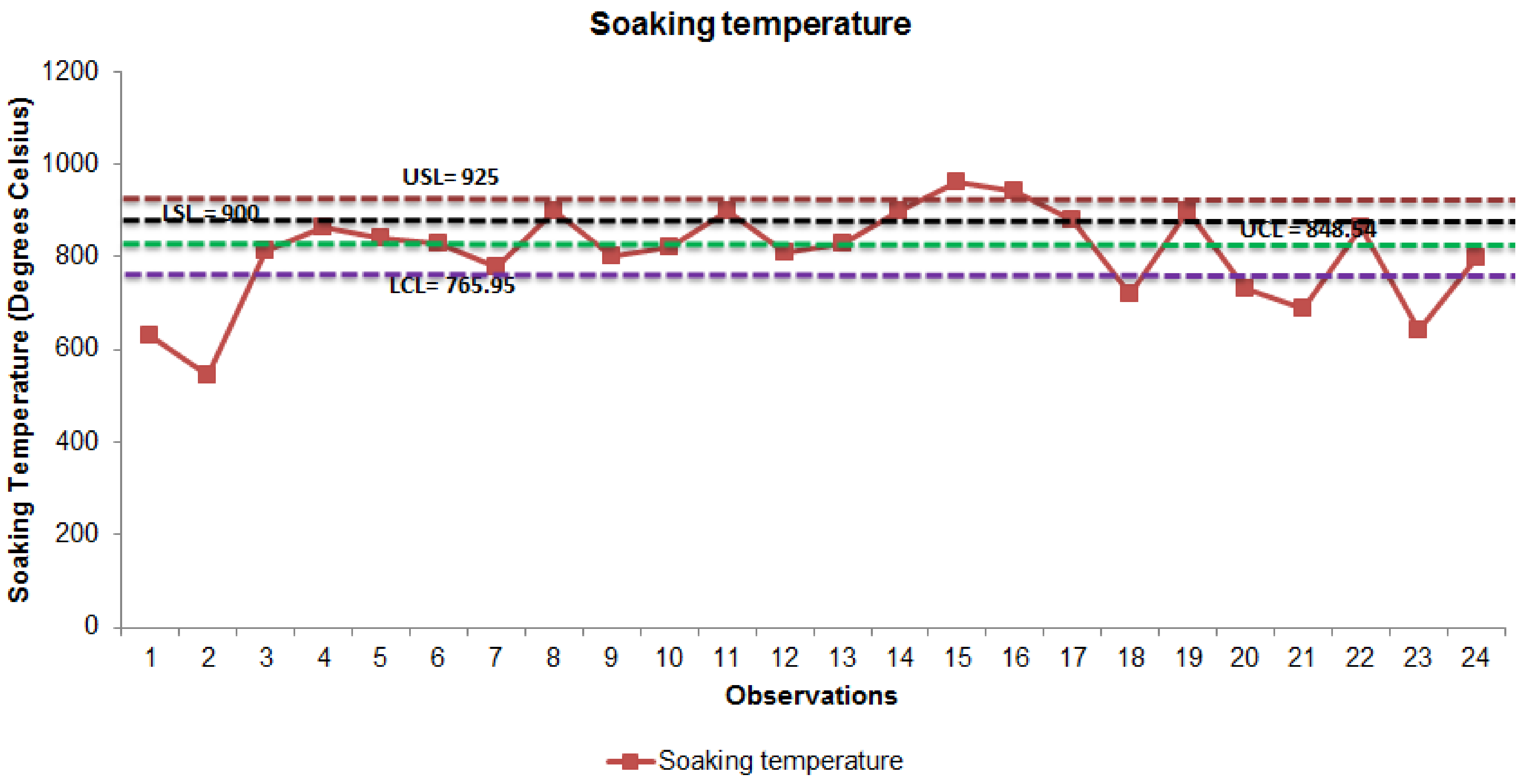


Figure 6-18: Soaking temperature

At the Foundry when heat treatment is done incorrectly, the graph shows the incorrect curve according to specification and a re-heat is done. This is done to ensure the correct matrix structure is achieved. During the observations at the Foundry from June to September 2015, it was observed that 29% of the time the business had to re-heat and 71% of the time heat treatment was done correctly. This has been charted in Figure 6-19. When heat treatment is done incorrectly, the castings will be brittle and fracture when used.

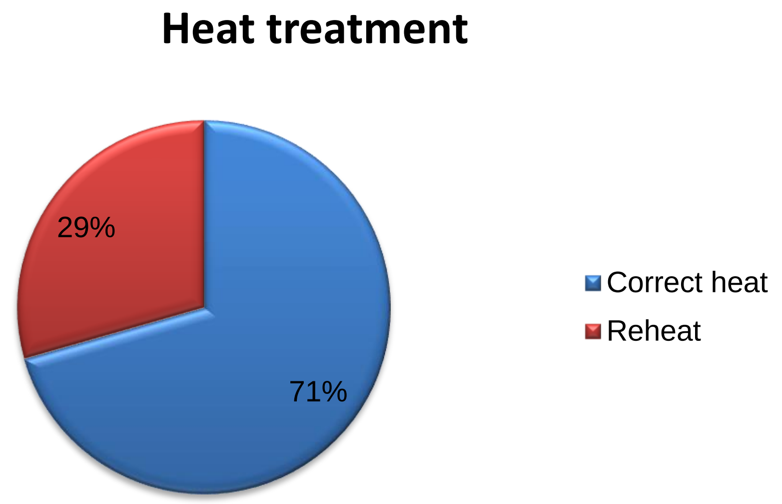


Figure 6-19: Reworks in heat treatment

It is imperative that soaking time is between 3 to 5 hours. On average using the observations indicated the soaking time at Foundry is 2hours 30 minutes. When heat treatment is done incorrectly and correctly the curves as shown in Figure 6-20 are obtained. The correct curve is shown on the left on Figure 6-20 and the incorrect curve which results in a reheat is shown on the right.

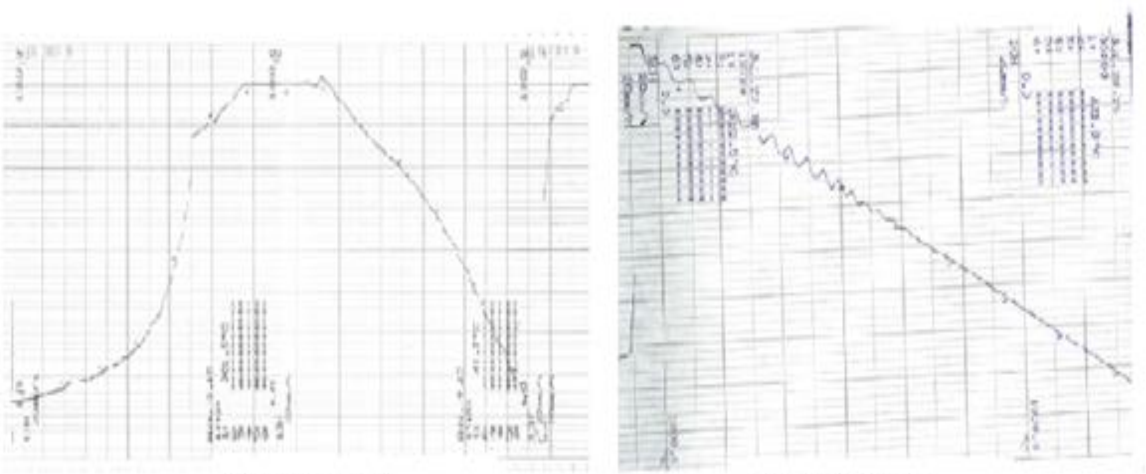

Correct curve
Incorrect curve

Figure 6-20: Heat treatment curve

6.7 Casting Defects

Transnet Foundry uses silica sand for casting and it has many disadvantages such as a high thermal rate which can cause expansion defects in castings. Metal penetration, sand burn and carbon defects occur most commonly within ferrous metals due to high casting temperature, high density and the reactivity of their oxides to silica sand. The use of water based coatings on cores and moulds mixed with chemically bonded sand, can affect the strength of the bond and may give rise to casting defects. The defects that have been experienced at Foundry from July to September 2015 can be seen in Figure 6-21.

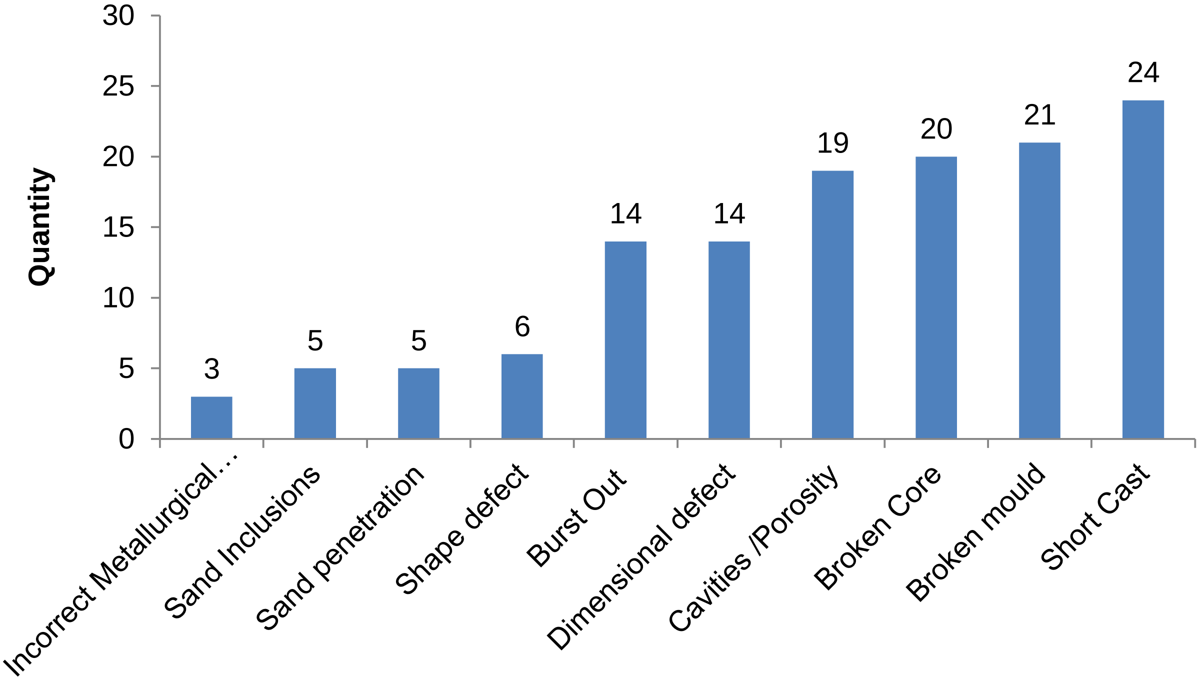


Figure 6-21: Casting defects

Sand inclusions in moulding sand can be caused by break up of mould sections and in resin bonded sand. Sand inclusions are caused by low core strength and excessive core mismatching. Shape defects can be caused by loose box pins, inaccurate pattern dowel pins or carelessness in placing the top on the bottom mould. Short cast defects are caused by an insufficient quantity of liquid metal in the ladle and premature interruption of pouring due to workman’s error.

6.8 Non Compliance Reports (NCR)

Non-compliance reports are issued when one of two parties has bridged the service level agreement. An audit was conducted at Foundry in February 2015 and the results of the audit can be seen in Figure 6-22. The major findings included high scrap rate, gauges being out of calibration and unavailability of quality controllers on the workshop floor.

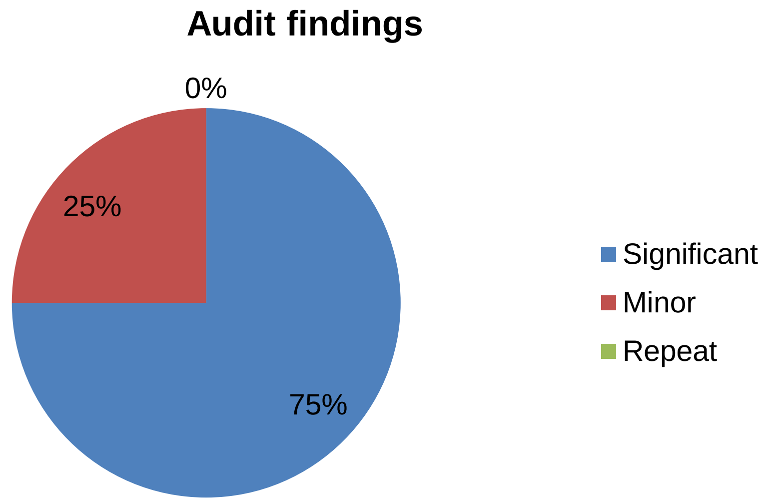


Figure 6-22: Audit findings

NCR's can also be issued by customers to the company mainly because the product that the business has sold, does not comply with specification.

6.9 Cost analysis

The details of the cost analysis for top centre castings and brake shoe holders can be found in Appendix 12-10.

6.9.1 Cost to manufacture top centre castings

The cost to manufacture top centre castings was calculated at R 578.51. The base cost for manufacturing top centre castings can be seen in Appendix 12-10.

Melt

When scrap is melted in the induction furnace, additives such as manganese, silicon and other metals are added.

Scrap

Scrap metal is used to charge the induction furnace and the cost of scrap per kg was calculated to be R3.85. Details of calculations can be seen in Appendix 12-11. The cost of melting one top centre casting has been calculated at be R965.19.

Electricity

The induction furnace consumes a lot of electricity when the scrap is being melted and prepared to become molten metal. The furnace electricity cost for one bogie is calculated at R103.67

Heat treatment

Heat treatment is a process that also consumes electricity. Heat treatment is done to ensure that castings are normalised and are stronger. The total heat treatment cost per top centre casting in winter is calculated at R80.89 and in summer it is R65.24.

Labour cost per department

Labour costs should be calculated in the manufacturing cost of the castings as value is added at each and every stage in the process. The total cost for labour for the value added to the top centre casting is calculated at R229.45 for one casting.

Dress after Weld

Dress to gauge is one of the fettling processes that has been outsourced. Dress after weld is the only process that has been left in-house. The cost of doing dress after weld on the top centre casting has been calculated at R15.57.

Total Cost to Manufacture Top Centre Casting

The total manufacturing cost for the top centre casting can be summarised as follows:

Raw materials (Sand + additives) = R578.51

+ Fettling raw materials = R15.57
+ Melting (Scrap + Additives = Charge) = R965.19
+ Electricity (Melting + Heat treatment cost) = R184.56
+ Labour cost = R229.45
= R1 973.28

6.9.2 Cost to manufacture brake shoe holders

Sand

The sand that is used to create moulds for brake shoe holders contains new and reclaims sand. Tests are done in the sand laboratory to ensure that the permeability, compactability and moisture among other things comply with specification. Total cost for sand and additives was calculated at R429.46. One mould contains four brake shoe holders and therefore the cost for one brake shoe holder would be R429.46 divided by 4 and it becomes R107.70.

Metal Additives

Preparing molten metal for brake shoe holders requires that metals such as manganese, flucast and silicon be added to the scrap that is being melted to ensure that the chemical composition complies with specification.

Scrap

To make brake shoe holders 7000kg of scrap metal is charged onto the induction furnace to form molten metal. Of the 7000kg scrap metal that is charged, 1000kg of that becomes slag and 6000kg becomes useful molten metal. When the observations were made 152 brake shoe holders were made. The cost of scrap per kilogram is R3.85. The calculated cost to prepare molten metal for one brake shoe holder was calculated to be R172.51.

Electricity cost: Melting furnace

It is important to calculate the cost of electricity consumed when melting scrap. The cost of electricity that is consumed per hour in the induction furnace is R681.58 per hour. The cost that was calculated for electricity for one brake shoe was calculated at R24.98.

Heat treatment cost

Castings require to be normalised to ensure that carbides are removed and the casting is strengthened. The total cost for heat treatment in winter for a brake shoe holder was calculated to be R20.22. In summer it was calculated at R16.30.

Labour cost

Labour costs were calculated to ensure value is added to the castings at different stages. The cost of labour for brake shoes was calculated at R192.66.

Dress after weld materials

The total cost for undertaking dress after weld was calculated at R28.89.

Total Cost for manufacturing Brake shoe holders

The total manufacturing cost of brake shoes was calculated at R546.63.

6.9.3 Cost of quality

For any Foundry it is imperative to design a quality system that includes the concerns of the customer. This can be done by utilising the existing quality standards to calibrate the process performance and product quality. Rejection diagnosis sheets can be drawn to quantify non-conformance costs related to internal quality standards.

A summary table has been drawn up to illustrate the instances when in the casting process, there were deviations from the prescribed specification. This is shown in Table 6-12.

Table 6-12: Process out of specification

Section in the plant	**Process**	**Property**	**Out of specification%**
Green sand	Return Green sand	Fines	36%
	Return Green sand	AFS	75%
	New sand	Fines	44%
	New sand	AFS	84%
Resin Bonded sand	Mould making-Chemically bonded sand		66%
Moulding	Mould making-Chemically bonded sand		1.56%
Furnace	Melting		11%
Fettling	Dress after weld (Do not gauge)		15%
Fettling	Dress after weld (Rework)		6%
Heat Treatment	Heat treatment		29%

Components of cost of quality

Prevention costs- These are costs incurred by an organisation when they try to investigate, prevent and reduce the risk of non-conformity. These costs are planned and are associated with the design, implementation and maintenance of a total quality management system (Zimwara, Mugwagwa, Maringa, Mnkandla, Mugwagwa, & Ngwarati, 2013).

The Foundry in the financial years 2013/2014, 2014/2015, 2015/2016 sent their employees to TUV Rheinland for the ISO 9001 Internal Auditor course. Table 6-13 shows the table of the number of attendees who have attended the internal audit course and some people who are still to attend the course in 2015/2016.

Table 6-13: Audit training course at TUV Rheinland

Financial year	Number of attendees	Cost	Total costs
2013/2014	3	R 4 000.00	R 12 000.00
2014/2015	4	R 4 530.00	R 18 120.00
2015/ 2016	5	R 5 392.20	R 26 961.00

In 2013/2014 the Foundry sent 3 people and in 2014/2015 they sent 4 people and in 2015/2016 the business is planning to send 5 people for training. By 2016 the Foundry business would have spent R57 081.00 towards prevention costs. Figure 6-23 shows the prevention costs which the Foundry has taken to ensure defects are minimised.

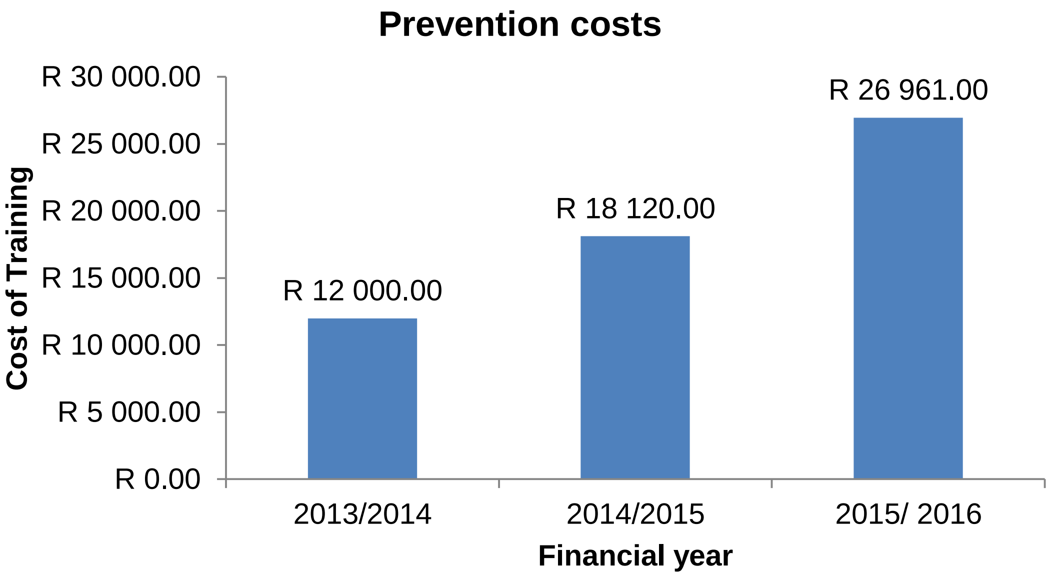


Figure 6-23: Prevention costs

Internal failure costs: These costs arise from failure of products to conform to customer requirements and these can be categorised into costs of scrap, rework, retest, re-inspection, modification, downtime, overtime and corrective action (Zimwara, Mugwagwa, Maringa, Mnkandla, Mugwagwa, & Ngwarati, 2013). The rework costs for the top centre casting were calculated. The costs for rework can be seen in Table 6-14. The top centre castings have a total of R320 016.00 for the period of three months in which observations were undertaken.

Table 6-14: Rework costs - Top centre casting

Selling price TCC	R 8 475.00				
Product	Process	Total number of casting	Rework (%)	Reworked castings	Cost of rework
Top centre casting	Dress after weld	236	16.00%	38	R 320 016.00

The rework costs for the brake shoe holders were calculated and they can be seen in Table 6-15. The cost of rework for brake shoe holders was calculated at R522 245.93 for a period of three months in which observations were done.

Table 6-15: Rework costs - Brake shoe holders

Selling price TCC	R1170.85				
Product	Process	Total number of casting	Rework (%)	Reworked castings	Cost of rework
Top centre casting	Dress after weld	7434	6.00%	446	R 522 245.93

Reheat is another form of rework for heat treatment of castings. However when normalising of castings is done incorrectly, a reheat is undertaken and this consumes electricity in the Foundry. The normalising cycle for brake shoe holders and top centre castings is 12 hours. In winter, if a reheat is done, the cost would be R4 094.00 and in summer it will be R1 658.00. The total internal failure costs for brake shoe holders and top centre castings for the period under observation is R 842 261.93.

Appraisal costs – These are costs associated with evaluation and verification of purchased goods, services and processes by an organisation to ensure they are within specified requirements. The examples include production trial test costs, test and measurements costs (Zimwara, Mugwagwa, Maringa, Mnkandla, Mugwagwa, & Ngwarati, 2013). Appraisal costs in the Foundry include situations when sand is tested before it is purchased to ensure that it has all the properties that are required for casting excellent quality moulds.

External failure costs

These are costs which an organisation incurs after delivering non-conforming products to the customer. These include equipment failure, downtime and warranty (Zimwara, Mugwagwa, Maringa, Mnkandla, Mugwagwa, & Ngwarati, 2013). External failure costs at the Foundry include the non-compliances that are received from customers when defective products are delivered.

On the Transnet's SAP NCR Dump there are 53 non-compliances that have been received from external customers. The cost of repairing rejected components by customers can be obtained from a spread sheet that has been formulated. The repairs need cutting, melting, dress to gauge and dress after weld. Table 6-16 shows the external failure costs that are incurred by the business when castings are received from external customers. A template has been created covering the instances when a casting has to go through the entire process again. The spread sheet has in built formulas and when the number of rejected castings is entered, it generates the cost of reworking the casting. Table 6-16 shows the snap shot of how the spread sheet calculates.

Table 6-16: External failure costs

Product	**Number of Castings to be repaired**	**Cost incurred**
Top centre casting	10	R 195 536.34
Brake shoe holder	53	R119 810.74

The total external failure costs for the time that the observations were undertaken as shown in Table 6-16 has been calculated at R315 347.80.

The summary for the cost of quality for the Foundry business can be shown in Figure 6-24. Internal failure costs have the highest cost followed by external failure. Appraisal costs could not be quantified and in essence there is a cost attached to them.

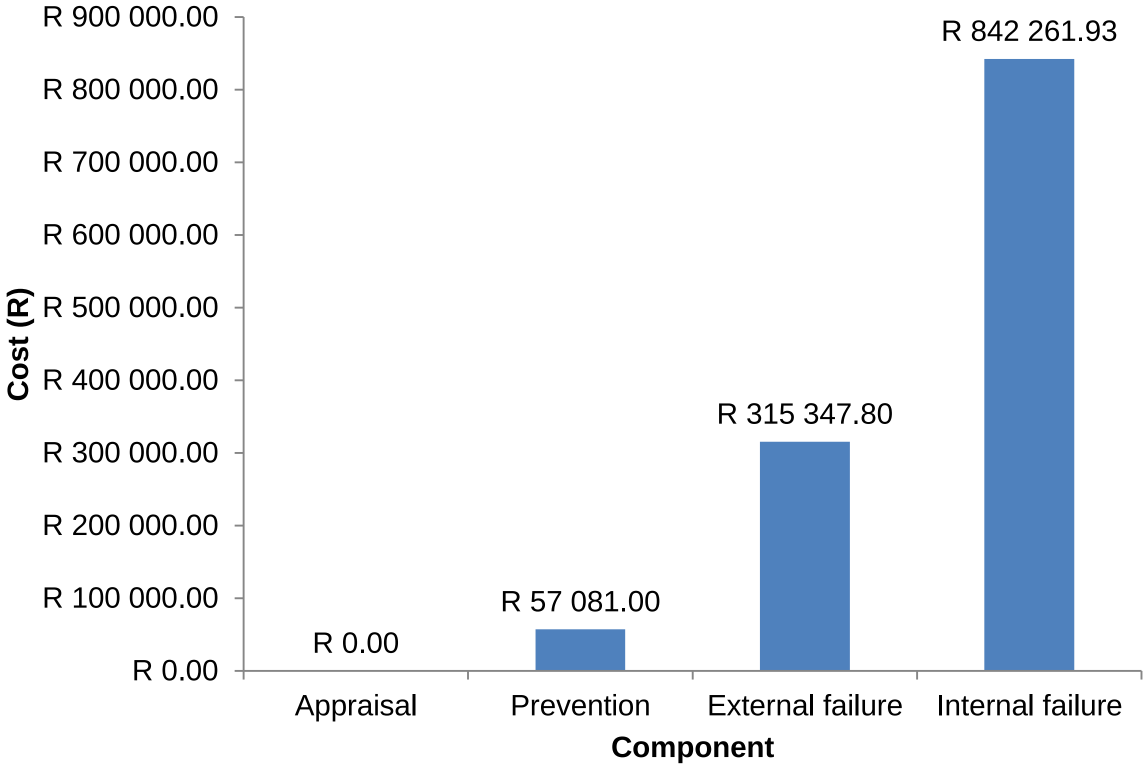


Figure 6-24: Cost of Quality

6.9.4 Impact of defects on productivity

On an annual basis, the Foundry is given a target that they should reach for the sale of the castings. In the financial year 2014/15 the Foundry was given a target of 8878 units for the top centre castings. The brake shoe holders type 17 had an annual target of 41500 units and the same target holds for the brake shoe holders type 18 which is the right side. The table indicates that for brake shoe holders the actual productions for the anticipated targets were not reached. Productivity on brake shoes was calculated to be 47% and on the top centre castings it was calculated to be 53% as shown in Table 6-17.

Table 6-17: Foundry sales

Customer	Component	Demand 2014/15	Demand per month	No. of moulds produced	Total no of castings produced per month	Price Per Component	Productivity	Target Sales Per Month	Actual sales per month
Rolling Stock Equipment	Brake Shoes /17	41500	3458	409	1636	R 1 170.85	47%	R 4 048 799.30	R 1 915 510.60
Rolling Stock Equipment	Brake Shoes /18	41500	3458	409	1636	R 1 170.85	47%	R 4 048 799.30	R 1 915 510.60
Wagons	Top centre casting	8878	740	174	390	R 8 475.00	53%	R 6 271 500.00	R 3 305 250.00

Anticipated targets were not reached as a result of defects that occur in the process. Some of the defects require the entire process to be followed again.

On a monthly basis the Foundry is expected to sell brake shoe holders to the value of R4 048 799.30. However they only make R1 915 510.60 and for the top centre castings although the target sales are R 6 271 500.00 and they are producing only R305 250.00. This can be illustrated by Figure 6-25.

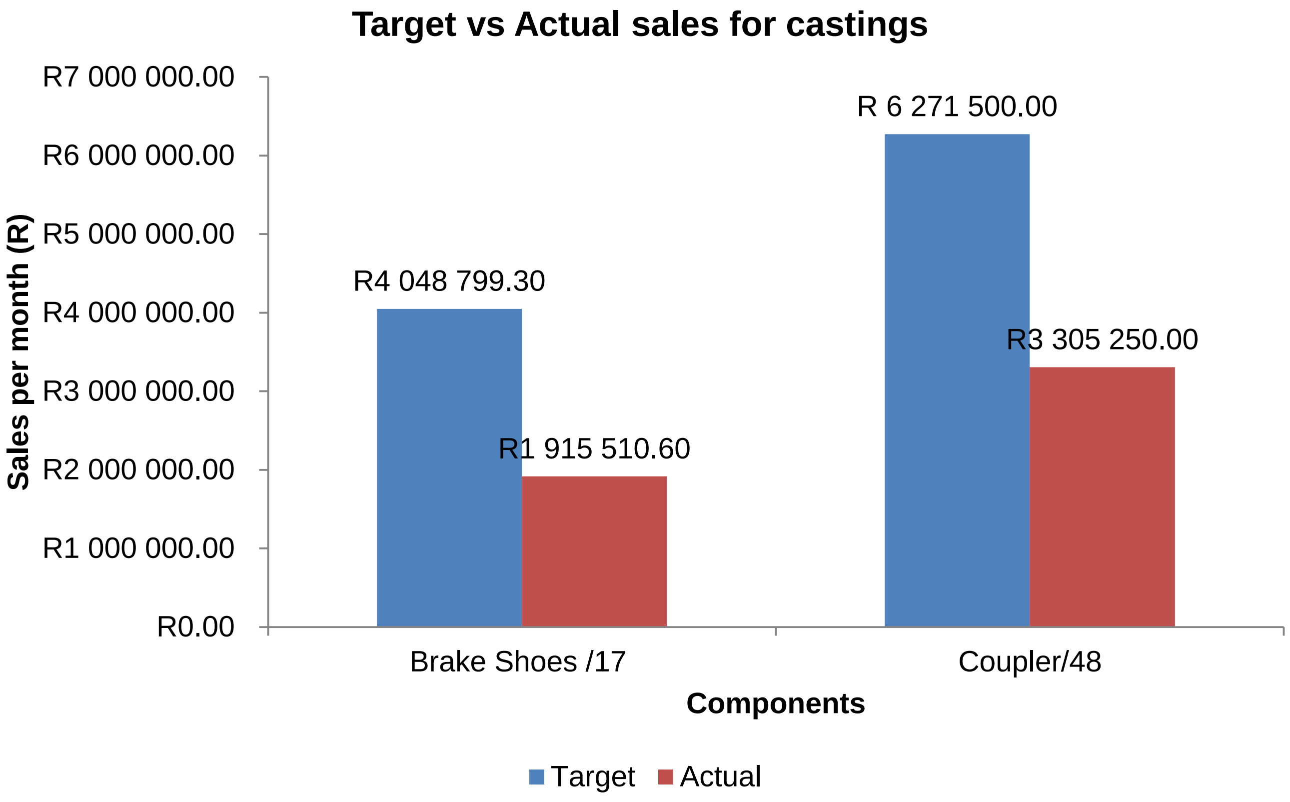


Figure 6-25: Target vs. Actual sales

6.10 Qualifound framework

Qualifound system has been installed and tested on Portuguese medium sized aluminium foundry and it can be tried at the Transnet Foundry. Qualifound system will enable Transnet Foundry to calculate the percentages of rejected castings. The program is also able to show the cost of non-conformities for the same batch of castings. It is important that the foundry knows the most relevant defects in total scrapped parts and in which operation, procedure or parameter is their origin. This can help in characterizing their contribution of a certain operation/parameter for the total rejected castings produced by the foundry.

After the software installation, measures were taken to reduce non-conformities in the line and consequently the rejections cost have been decreasing every year and this has been followed by a significant increase on the casting sales. This behaviour suggests an important contribution of Qualifound in the analysis and decisions that were taken which contributed to the significant increase on the company's competitiveness.

The Qualifound system is important in that it is a very useful support knowledge for the existing know how in castings production. At the foundry currently there is no program that analyses defects and the analysis is currently done on Microsoft excel. In this study, data was collected from Foundry records. The data is loaded on SAP system and analysis is manually done on Microsoft Excel. The value of rejected castings in the study was manually calculated and if Qualifound program had been installed the value of rejected castings could be quantified in economic terms in an integrated way. The causes of rejections as well as their consequences can be analysed with Qualifound and this can help Transnet foundry

The cost of quality of quality if Qualifound system is in place would be also programmed on easily. The calculation of prevention, external failure, and internal failure and appraisal costs would be easy to draw from the system especially if such functions have been custom programed for Transnet Foundry. The cost to install Qualifound should be compared to R1 214 690.73 for the financial year 2014/2015.

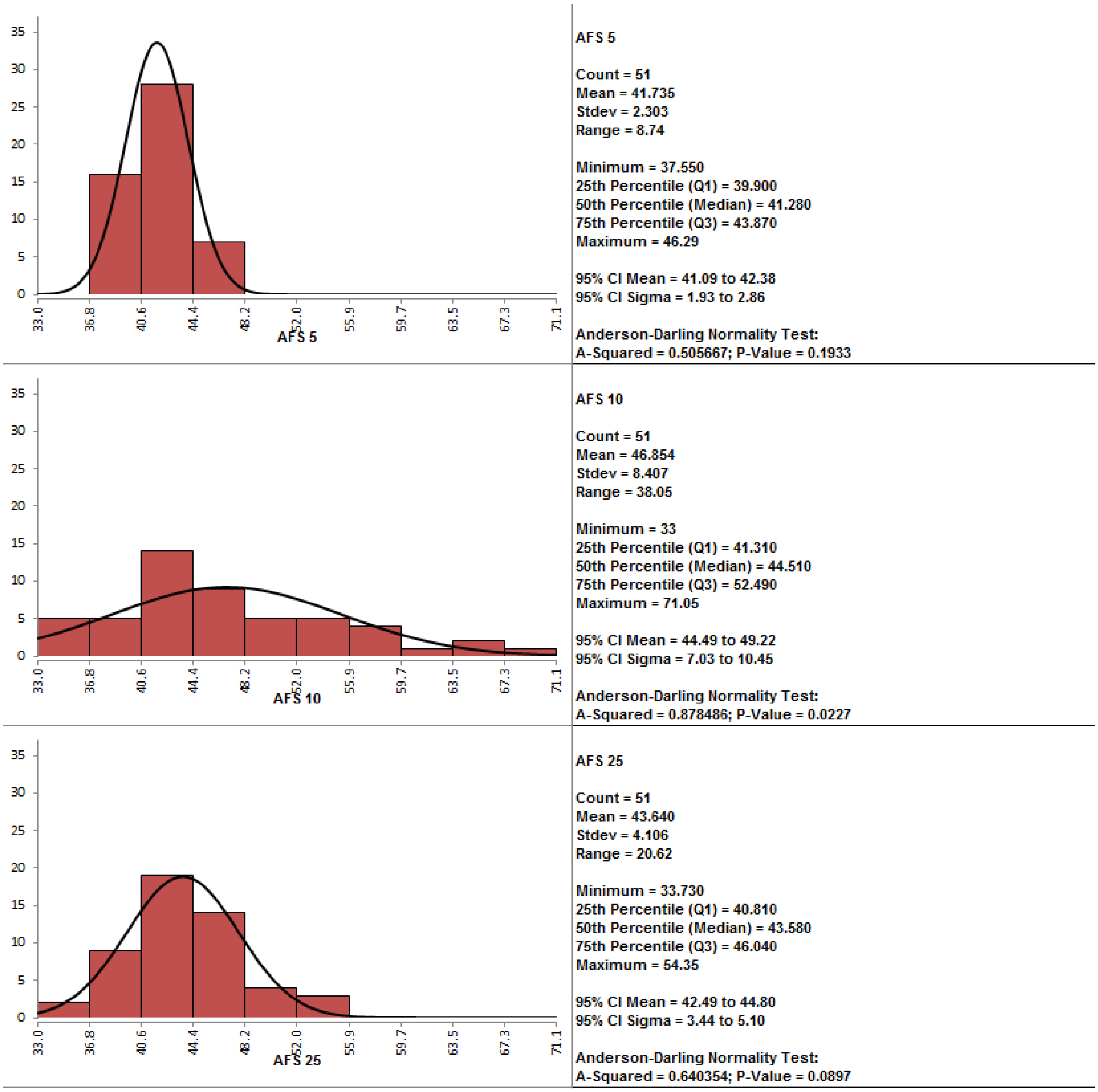
6.11 Statistical justification and application

In the study, sample size is concerned with how much data is required to make a correct decision and more data enables more accurate decisions to be made. In the study observations were taken from the production line for 6 months. Table 6-18 shows a summary of the samples collected.

Table 6-18: Samples collected

Process	Samples collected/Observations
New sand	40
Green sand	200
Chemically bonded sand	62
Moulding green sand	25
Moulding chemically bonded sand	55
Melting	43
Dress after weld	46
Heat treatment	34

Data analysis was done to check if the AFS and Fines data analysed statistically was normally distributed. Analysis was done to check if the data is normally distributed and the results can be seen in Figure 6-26. The null hypothesis is that the data is normally distributed.



```
AFS 5

Count = 51
Mean = 41.735
Stdev = 2.303
Range = 8.74

Minimum = 37.550
25th Percentile (Q1) = 39.900
50th Percentile (Median) = 41.280
75th Percentile (Q3) = 43.870
Maximum = 46.29

95% CI Mean = 41.09 to 42.38
95% CI Sigma = 1.93 to 2.86

Anderson-Darling Normality Test:
A-Squared = 0.505667; P-Value = 0.1933
```

```
AFS 10

Count = 51
Mean = 46.854
Stdev = 8.407
Range = 38.05

Minimum = 33
25th Percentile (Q1) = 41.310
50th Percentile (Median) = 44.510
75th Percentile (Q3) = 52.490
Maximum = 71.05

95% CI Mean = 44.49 to 49.22
95% CI Sigma = 7.03 to 10.45

Anderson-Darling Normality Test:
A-Squared = 0.878486; P-Value = 0.0227
```

```
AFS 25

Count = 51
Mean = 43.640
Stdev = 4.106
Range = 20.62

Minimum = 33.730
25th Percentile (Q1) = 40.810
50th Percentile (Median) = 43.580
75th Percentile (Q3) = 46.040
Maximum = 54.35

95% CI Mean = 42.49 to 44.80
95% CI Sigma = 3.44 to 5.10

Anderson-Darling Normality Test:
A-Squared = 0.640354; P-Value = 0.0897
```

Figure 6-26: Normality test

From Figure 6-26, the p value for AFS 5 is 0.19, AFS 10 is 0.02 and AFS 25 the p value is 0.0897. This indicates that data might be normally distributed as $p > 0.05$ for AFS 5 and AFS 25.

Analysis of Variance (ANOVA) was done as we wanted to compare more than two means with each other. A graphical analysis was done using box plots as shown in Figure 6-27.

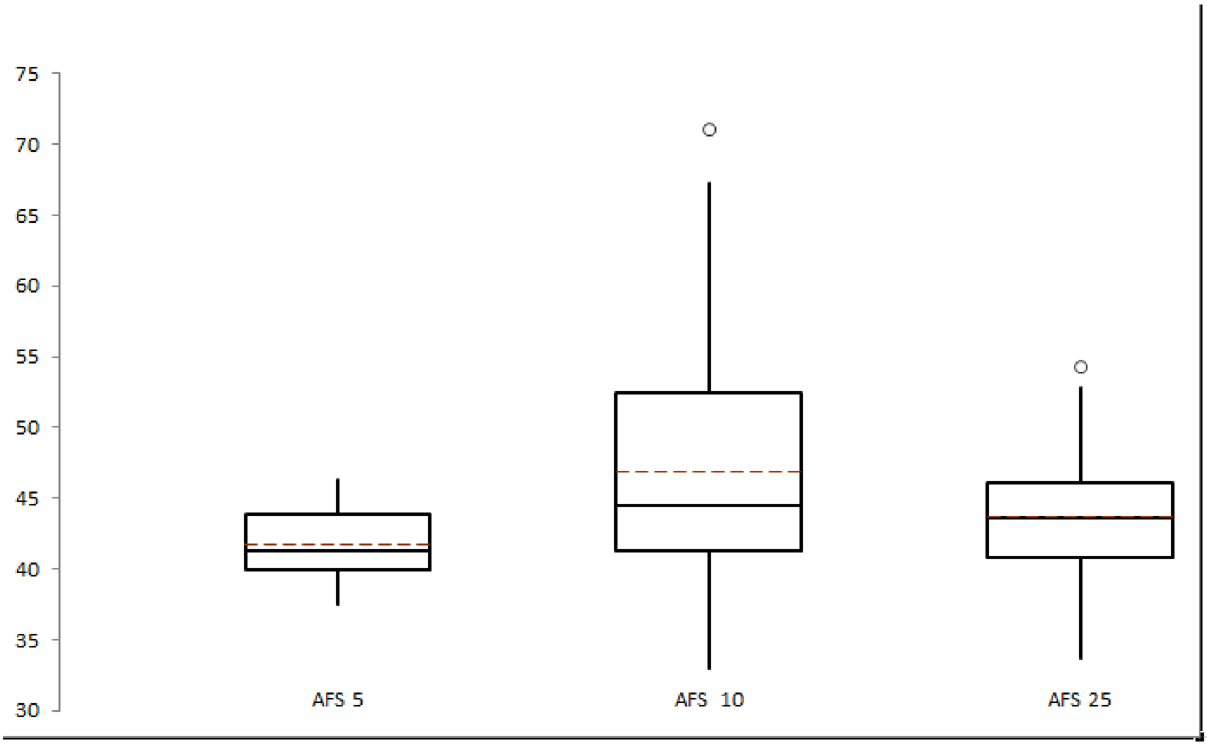
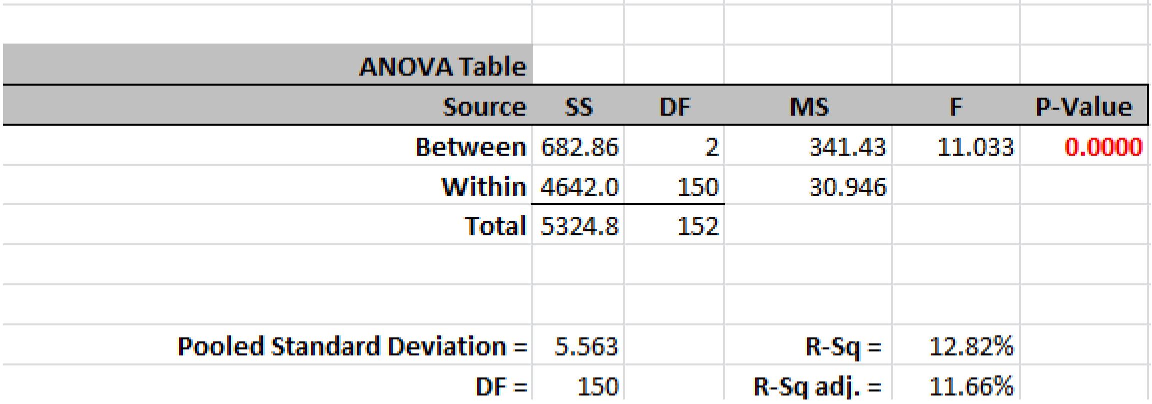


Figure 6-27: Box Plot for AFS data

From the graphical view, the box plots indicate that the means may be different and that the variances might also vary. Figure 6-28 indicates that $p < 0.05$ and this means that we can reject the null hypothesis that data is normally distributed.



ANOVA Table					
Source	**SS**	**DF**	**MS**	**F**	**P-Value**
Between	682.86	2	341.43	11.033	0.0000
Within	4642.0	150	30.946		
Total	5324.8	152			
Pooled Standard Deviation =	5.563		**R-Sq =**	12.82%	
DF =	150		**R-Sq adj. =**	11.66%	

Figure 6-28: ANOVA Table

6.12 Summary of Data Analysis

The data that was collected highlights the quality issues in the Foundry such as non-compliance. The common defects include short cast, sand inclusions, broken mould, porosity and sand burst out. The total cost of quality was calculated to be R 1 214 690.73. The impact of defects on productivity was also analysed for the financial year 2014/2015 and it was calculated to be 47% for the brake shoe holders. The target for the Transnet Foundry for the financial year 2014/2015 was R4 048 799.30 however, actual productivity in sales amounted to only R1 915 510.60. For the top centre the estimated target for the financial year 2014/2015 was R6 271 500.00 and the actual productivity amounted to only R3 305 250.00. Statistical justification shows that data is not normally distributed.

7. DISCUSSION

This chapter checks the extent to which results obtained in the study answer the research question. The chapter also compares the results with the literature and highlights how the research objectives were met. The research findings will be discussed as per source and will be compared with each other.

The purpose of the discussion was to determine what improvements to the quality system of the Transnet Foundry would contribute to increased productivity, throughput and profitability.

7.1 Sand Preparation

According to Brown (2000) Foundries should conduct standard tests for green sand which include compactability, moisture, specimen weight, permeability, green compression strength, dry compression strength and methylene blue clay content. Results indicate that at the Transnet Foundry, total clay, active clay, LOI, volatiles and green shear are not measured. Brown (2000) describes that the standard tests that should be conducted for chemically bonded sand including Sieve, Mesh, % Retained Factor, Product, %Fines, Bulk density and pH.

The Transnet Foundry does not conduct these tests in chemically bonded sand. The quality issues that arise are as a result of inadequate sand tests. This results in defects propagating through the entire system. Grain Fineness Number and Fines measured for both new and return sand. According to Brown (2000), the AFS for return sand has the specification AFS (45-60) and for new sand the AFS ranges from (45-55). Results indicated a non-compliance of 75% with return sand and 35% with new sand. New sand does not comply with specification as there is no strict control and monitoring of incoming sand from suppliers. With return sand, defects occur because sand is over used beyond its useful life resulting in defects.

With regard to fines content, new sand results indicated that 36% of the fines complied within specification for return. The Foundry has a poor data recording system and the collected data is not utilised as a means of reducing quality issues that are currently experienced in the business. Quality issues that are experienced at sand preparation include lack of metallurgical background of sand laboratory staff and failure to adhere to standard operating procedures. Quality is not built into the process. Observations indicated that chemically bonded sand preparation is a very manual and labour intensive process and there are currently no records of mixing ratios. This causes defects to occur especially if there are imbalances in the mixing ratios for resin and catalyst. Significant improvements in monitoring quality at sand preparation can be done by conducting sand tests as indicated by the specification Brown (2000). Laboratory records were analysed and the Fines and AFS were the parameters that were measured to check if the sand used complies with specification. In the chemically bonded sand area the sand in three machines was analysed which include 5, 10 and 25 ton machine. Results indicated that for the parameter AFS the sand in 5 ton machine was out of specification by 91% and for the 10 ton, it was 58% out of specification and for the 25 ton machine it was 50% out of specification.

Control charts were plotted for the parameter AFS for the 5 ton machine and the control chart indicated the process was out of control. For AFS for the 10 ton machine, the control chart indicated that its process was out of control limits and specification limits and the AFS for the 25 Ton machine was out of control indicating that the processes for all the machines were out of control. The control charts for Fines for the 5, 10 and 25 ton machines were also out of control and there was a lot of variation. Process capabilities for the three machines were calculated. According to Heizer & Render (2014), Cp of less than 1 indicates the process is out of control. The calculated Cp for all the three machines were less than one and this means that the three machines that are used for processing chemically bonded sand are not capable of producing according to specification. These machines need calibration and the artisans should be deployed to conduct a failure mode effect analysis on them to ensure that they produce sand according to customer requirements.

7.2 Mould making

According to Chaudhari &Thakkar (2014), moulding material defects are caused as a result of the characteristics of moulding and they are caused by the erosion of the moulding sand by the flowing molten metal. In some instances, it is a result of the moulding sand not having enough strength, higher pouring temperatures and the faulty mould making procedure (Chaudhari & Thakkar, 2014).

At the Transnet Foundry mould making is done in the green sand area and chemically bonded sand area. According to Kay &Nigel (2001), defects occur in sand moulding especially when a molten metal runs over the surface of the green sand mould and the moisture in the sand is converted to steam that permeates the sand grains. Root cause analysis conducted on the green sand, indicated that defects that occur are the result of standard operating procedures not being followed, lack of quality consciousness, operators are target driven and they have more interest in volumes of castings produced as opposed to quality. Volumes of moulds produced are the key performance indicators for productivity in moulding. From observations, it was noted that there is also lack of specialisation and training as the operators are continuously rotated. According to Alena, Marianna, & Dana (2010) unprofessional management policies and procedures and poor work discipline, or lack of training, are reasons why quality issues arise in the Foundry.

Furthermore the reclaim green sand is used beyond useful life in the Foundry and Kay & Nigel (2001) advises that when any amount of one component in sand is out of balance, the potential for defects arises. In chemically bonded sand quality issues occur as a result of usage of water based coatings. Brown (2000) warns against use of water-based coatings on chemically bonded sand moulds as it affects the strength of the bond and may give rise to casting defects due to surface friability of the mould. Quality issues that arise in chemically bonded sand moulding are the same as in green sand except this process is manual and labour intensive and moisture content is not measured. Moreover, the method that is used for turning the moulds causes breakages.

According to Alena, Marianna, & Dana (2010), the use of improper tools, equipment, appliances, or patterns can cause quality issues to arise. The patterns in the green sand area are kept next to the production line and are not cleaned. The consequences of keeping patterns in the production line are that patterns get damaged and the wear and tear of patterns has an effect on the dimensions of castings produced. Moreover maintenance of mould patterns is also outsourced and this delays production especially when mould patterns go for repairs.

In green sand, mould hardness is measured as the key product characteristic and in chemically bonded sand, the number of broken moulds is also measured. Data records from Foundry moulding lines records were analysed. In green sand moulding, control charts were drawn for the mould hardness. The control chart showed that a significant number of points fell above the upper control limit, thus the process was not in control. The process capability calculated was unrealistic leaving room for defects to occur. Further calculations for the control limits were done with alpha of 10% and there were no improvements in the upper and lower control limits. This means that the hardness of the green sand moulds cannot be ascertained and as a result quality issues arise. In chemically bonded sand, the number of broken moulds is measured. The moulds break as a result of the methodology used in turning top and bottom mould. The total breakage of moulds in chemically bonded sand was calculated to be 1.56%. According to Kay & Nigel (2001), Foundries can consider the following improvements in the sand moulding system:

- Adding cellulose to the sand to provide a place for expansion to occur.
- Lowering the moisture content of the moulding sand increases the overall mould strength.
- Lowering the pouring temperature of the metal (eliminate excess super heat) which reduces sand expansion.
- Lowering the temperature of the moulding sand from return sand system to increase the strength properties of the sand.
- Increasing the clay content of the sand especially bentonite for better hot strength properties.
- Decreasing the amount of fines in the sand. Fines tend to absorb water increasing overall mould moisture without increasing mould strength.
- Avoiding over-ramming or over squeezing the mould as this pushes moisture closer to the mould surface increasing probability for defects.

7.3 Melting

According to Alena, Marianna, & Dana (2010), defects may occur in melting and may be attributed to the use of unsuitable or unsatisfactory raw materials. In melting, it is important that the scrap metal that is charged into the induction furnace complies with the specification of mild steel. Owing to the pressure to reach the required tonnage outside supplier add scrap metal which is not mild steel. Incoming quality inspection is not done strictly by quality personnel and as a result, other metals are melted which are not prescribed in the specification. According to Alena, Marianna, & Dana (2010), the composition of steel melted in the induction furnace changes little during melting so that careful selection of charge materials is necessary. The melting process allows for testing only when the scrap is molten. The spectrometer test ensures compliance of the chemical compositions as prescribed on the melting specification. When deviations occur, more additives of different metals are added until the correct composition is reached.

The conducted root cause analysis highlighted that quality issues occur as a result of non-compliant scrap being used. Observations at the melting station highlighted that weigh scales used are incorrectly calibrated. The key product parameter that was measured in melting was the chemical composition. Data records from the spectrometer laboratory were analysed to check for compliance. Results indicate that the observations data complies with specification although there are little differences which can occur. Accordingly to Alena, Marianna, & Dana (2010), aspects of the casting quality affected by melting and steel making practise include: de-oxidation effects, sulphides, inclusions, gas porosity and hot tearing. Improvements that can be implemented to reduce defects occurring in melting should involve strict control of incoming scrap material.

7.4 Casting

According to Ott, (1997), it is imperative to control the flow of metal into the mould cavity at the rate needed to avoid cold metal defects in the casting. Quality issues that occur in casting includes producing defective castings such as shot cast when little metal has been poured to a mould and the casting gets scrapped. According to Alena, Marianna, & Dana (2010), running and gating systems encourages thermal gradients within the casting helping to produce sound castings.

7.5 Dress after weld

Transnet Foundry is now only responsible for dress after weld. Other fettling work which includes shake out, shot blasting, cutting and dress to gauge have been outsourced. The challenges that come with outsourcing especially when referencing the quality of the castings are that outside suppliers have not been mandated to conduct quality checks. Moreover from observations, the subcontractors responsible for fettling were not given any formal standard operating procedures by their quality department to guide the fettling work.
Outsourced suppliers simply do the fettling work that needs to be done on the casting and they leave all the defects to be repaired at Transnet in final inspection. There are costs that the business incurs, especially in cases when defective castings have been fettled and get rejected at the final inspection. The casting would need to be re-melted and goes through the entire process again. Outsourcing has drawbacks as it gives the power to the supplier leaving Transnet with less control to check for defects. Dress after weld is the responsibility of the Transnet Foundry as it allows them the opportunity to fix the surface defects through welding. However, not all the defects can be repaired by welding.

Data was collected from the dress after weld records. Of the records collected, a total of 7434 brake shoe holders and 236 Top centre castings were inspected in the three months. 79% of brake shoe holders were accepted to be of good quality whilst 15% of them did not gauge and 6% became rework.

Quality issues that arise as a result are that the defects are discovered at the end of the process. It is requirement that the castings get delivered to the customers without defects yet some of the castings leave the Foundry with defects and the defective castings are returned. Consequently, NCR’s are often raised against the business .The Foundry is a target driven environment and in most cases defects are detected at the customer premises. The customers then charge penalties to the Foundry for delivering products that do not meet their requirements.

7.6 Heat treatment

According to Brown (2000), heat treatment of the castings will eliminate carbides in thin sections to produce more consistent matrix structures for a given structure. The mechanical properties are often improved by heat treatment, especially by normalising. In heat treatment, the key product parameters that are measured include heat treatment curve and the soaking temperature. Top hat ovens have inbuilt sensors that plot a graph during the heat treatment process to show whether the castings have been normalised according to specification. It is imperative that all the phases involved in normalising are reached and this includes ramp up, soaking phase and cooling.

For castings to achieve a consistent matrix structure the desired shape of the heat treatment graph must be achieved. If the desired shape is not achieved, a reheat is done. According to Brown (2000), carbides in the thin sections of castings can be eliminated by soaking the castings at 900-925 degrees for 3 to 5 hours. During the time that observations were undertaken, re-heat which can be equated to reworks in heat treatment was calculated to be 29%.

When heat treatment is done incorrectly, the castings were brittle and would fracture easily when they are used. Soaking time should also be between 3 to 5 hours and at the Foundry the time is 2 hours 30 minutes on average.

Control charts were drawn for the heat treatment process and it indicated that the process is not in control. There were many data points that were outside control limits. Process capability was also calculated and a Cp result of less than one was obtained. This indicates that the heat treatment process is out of control. The top hat ovens that are used in normalising the castings need to be repaired for the process to be able to produce castings that comply with hardness requirements from customers. The inbuilt sensors in the top hat ovens need to be calibrated and failure mode effect analysis should be done on all the heat treatment machines.

7.7 Casting defects

According to Rajkolhe & Khan (2014), casting defects can be classified as filling related defect, shape related defect, thermal related defects and defect by appearance. Filling related defects include blowhole, sand burning, sand inclusion, cold shut, misrun and porosity, thermal defects include cracks or tears, shrinkage and sink mark. The research indicates that the major defects that are known to cause problems in the Foundry include porosity, sand inclusions and burst out. As indicated by Rajkolhe & Khan (2014), these defects are mostly filling related defects. Porosity is caused by high gas pressure in the mould arising from moulding material having high moisture and/or volatile content and/or low permeability. Rajkolhe & Khan (2014), also suggests that porosity can be caused by pouring too slow. Foundry uses a manual system of pouring and human factors can lead to slow pouring.

Rajkolhe & Khan (2014), suggest that sand inclusions are caused by the pouring rate which may be too high, with a heavy impact against the mould wall surface resulting in erosion. Other factors include the ladle being too far above the pouring basin and pouring time may be too long. Burst out defects are caused by poor gating methods and by runners too close to the end. Producing defective products has financial implications to the business such as lost sales opportunity, rework costs and the wasted material. The major causes for the defects at the Foundry are that quality controllers currently working are not well trained and seem to have no accountability. There are currently no inspection documents that are completed and there is no accountability for a quality sign off. Furthermore welders responsible for dress after weld are not certified. Gouging tools are not available to remove the defects in the critical areas and this result in many castings being scrapped. Observations indicate that go/no/go gauges in the Foundry are not calibrated or validated and this brings the challenge of accuracy to the gauges. The Foundry has no numbering system for the gauges and they are not safely stored.

Observations indicate that mild steel is used to make gauges instead of tool steel and as a result their accuracy will not be maintained and their accuracy will not last. The laid out process is not enforced, resulting in components being heat treated before fettling, gauging and welding. This makes fettling very difficult and time consuming and second heat treatment will be required on a number of castings wasting money and time. Heat treatment increases the hardness by over 100 Brinell points according to Brown (2000) and this makes it difficult to do fettling work on the casting.

Casting defects can be caused by so many factors in melting. High content of sulphur in grey cast iron can cause a blowhole defect (Brown, 2000). Aluminium promotes hydrogen pick up from sand moulds and may cause pinhole defects in castings. To avoid defects on the casting surface, gating should provide rapid filling of the mould with minimum turbulence.

Defects can also be caused due to poor ladle maintenance and this need to be improved at the Foundry. The ladle needs adequate cleaning and defects arise from slag carried over from the ladles melting furnaces, from slag deposits left in the ladles after pouring and from the fusion of the ladle lining material (Brown, 2000).

7.8 Non Compliance reports

Non-compliance reports are received from unsatisfied customers especially if there is a service level agreement or a standard that has been breached. The non-compliance reports analysed in the study were obtained from the results of the audit that was conducted. The internal audit that was conducted at the Foundry investigated if the business follows the ISO 9001:2008 appropriately. Emphasis was placed on verifying the processes, facilities and technical expertise critical to the products being produced in alignment with the ISO 9000 standard.

The non-compliances were issued against the business for not having quality controllers on the Foundry production line. A finding stated that quality is only monitored at the end of the process. There was also a finding that the furnace gauges were out of calibration. According to Alena, Marianna, & Dana (2010), the improper use of equipment causes defects to occur. Calibration of equipment should be scheduled to be done on an annual basis. Quality documentation is not kept in a centralised place and this makes it difficult to trace and monitor trends in improvements and poor performance.

High scrap rate was another non-compliance issue that was raised. High scrap rate is caused by irregularities that happen in the casting process. Another audit finding that was raised involved mould pattern storage as it is not an access controlled area. Patterns are kept on the production line. A pattern register should be developed and the issuing out of pattern should be monitored and controlled to ensure that quality is assured. The minor findings from the audit accounted for 25% and the major findings accounted for 75% of the total result.

7.9 Cost of quality

According to Zimwara, Mugwagwa, Maringa, Mnkandla, Mugwagwa, & Ngwarati (2013), it is important to carry out quality cost analysis in an organization and this information can be used by management to identify quality costs, prioritize quality cost reduction activities and measure the success of such activities. This is so because quality costs are a tool that displays trends for management to act upon Zimwara, Mugwagwa, Maringa, Mnkandla, Mugwagwa, & Ngwarati (2013). The cost to manufacture each casting was analysed. For top centre castings and brake shoe holders, the costs for the different stages in the process were calculated. This was done so as to quantify the cost impact of defects at each and every stage. The total cost to manufacture top centre castings was calculated to be R 1 973.28 and the total cost to manufacture brake shoe holders was calculated to be R 546.63. The top centre casting is currently sold at R 8 475.00 and the brake shoe holders are sold at R1 170.85.

According to Gryna, Chua, & DeFeo, 2007, the components of cost of quality include preventions costs, appraisal costs, internal failure costs and external failure cost. Currently at the Foundry the cost of quality is not calculated and it is imperative to design a quality system that incorporates the concerns of the customer. According to Gryna, Chua, & DeFeo, 2007 , prevention costs are those costs that are incurred by the organisation when they try to investigate or reduce the risk of non-conformity. Transnet Foundry has spent money training people at TUV Rheinland for an internal audit course. In the financial year 2013/2014 they spent a total of R12000.00 and in the year 2014/2015 they have spent R18 120.00 whilst in the year 2015/2016 the Foundry is planning to spend R26 961.00 on training employees.

Training all along has been offered to management and in 2016 it would be profitable to train at least one representative from each process. The prevention costs are going up and there should be a declining decrease in the cost of scrap as well. According to Gryna, Chua, & DeFeo, 2007, internal failure costs are those costs that arise from the failure of products to conform to customer requirements and these can include the cost of scrap, rework and retest. The top centre castings that were made for the duration of this observation were 236 and of the total made 16% had to be reworked. The total number of castings reworked was 38 and the cost of rework was calculated at R320 106.00.

Over the three months that observations were undertaken, 7434 brake shoe holders were made, and a total of 446 were reworked. The total cost of rework was calculated at R522 245.93. The total costs for rework were calculated at R842 261.93.
According to Gryna, Chua, & DeFeo, 2007, the external failure costs are those costs that the organisation incurs after delivering non-conforming products to the customer. Over 53 non-compliances have been received and the cost of repairing returned components was calculated at R 119 810.74, for top centre castings it was calculated at R195 536.34 and the total external costs were calculated at R315 347.80. The appraisals costs were not calculated as there was no supporting data. The cost of quality principle in the Foundry

should be prioritised and enforced to ensure that the Foundry becomes a profitable business. The total cost of quality was calculated at R1 214 690.73 for the financial year 2014/2015 based on available data that was analysed.

7.10 Impact of defects on productivity

The impact of defects on productivity was calculated for brake shoe holders it was calculated at 47% productivity meaning that 53% productivity was lost due to defects. This percentage is equivalent to R 2 133 288.70 per month which on an annual basis amounts to a loss of R25 99 463.40 per year. Top centre castings productivity was calculated at 53% and the losses were calculated at R 3 305 250.00 per month which translates to R35 595 000.00 per year.

7.11 Qualifound Framework

According to Santos & Barbosa (2006) quality improvement has always been a concern in Foundries and this led to the development of a principle called Qualifound. The Qualifound tool has a qualitative and quantitative analysis built into it. Qualitative mode analysis enables relationships to be established between processes and operations. More than one defect can occur in one process and these defects that are related to the process can be identified. At the Transnet foundry, more than one defect can occur during moulding and this Qualifound tool can assist the business to identify the defects. The quantitative mode of the Qualifound tool helps in establishing relationships between orders and defects. This tool when adopted by the foundry will enable identification of all processes and operations from which defects may have originated. Qualifound tool will allow the integration of the quality methods that are currently not consistently used in the Foundry and it is will be developed and upgraded according to the Foundry needs.

7.12 Summary

The analysis of the research question related to what improvements to the quality system of the Transnet Foundry would contribute to increased productivity, throughput and profitability. The research question has been answered extensively as all the various processes in the Foundry have been measured, analysed. Moreover, all the quality issues have been identified for improvement. The research outcome indicates there are several improvements which could be done in the different processes at the Foundry. In the sand preparation process, all the tests for green and chemically bonded sand should be done. Incoming sand (new sand) needs to be tested and if non-compliant it must not be accepted. Return sand should be recycled as soon as the tests indicate that it needs to be changed. In mould making the research outcomes indicated that green sand mould hardness does not comply with specification and the specification limits should be reasonably adjusted to ensure the process can be controlled.

In chemically bonded sand there is a need for the machines used for mixing to be fixed and re-calibrated. If they cannot be fixed, a business case should be written to management to motivate for the purchase of new machines. Measuring equipment such as go/no/go gauges should be purchased for mould patterns in green sand. In melting, scrap metal should be monitored to ensure that it complies with specification. Casting defects can be reduced by ensuring that castings sent to customers are free from defects and in so doing, non-compliance reports from unsatisfied customers will be reduced. The objectives in the study have been met. All the quality issues in the process were identified and the total cost of quality was quantified and calculated at R 1 214 690.73 for the financial year 2014/2015. Lost productivity due to quality defects was calculated at 53% which is equivalent to R 2 133 288.70 per month and translates to a loss of R25 599 463.40 per annum.

7.13 Reliability of the research

Reliability of the research has been ensured in that the study has been conducted by one person who observed the actual production line from the beginning to the end. In this research an inter-observer reliability test can be conducted. There is no risk of variance for only one observer conducted this research. Data could only be collected at one place at a time. Some of the data was collected from historical records and analysed by the particular researcher. To ensure reliability and consistency, observations were done more than once in a section on different days and this eliminated bias in this study. Parallel form reliability was ensured by observing one operator conducting their work at a time and by so doing, this reduced parallel form risk.

8. CONCLUSION

The investigation of the quality defects at the Foundry can be regarded as a success. This can be deduced from the study conducted which looked at the various processes in the Foundry including sand preparation, mould making, melting, casting, dress after weld and heat treatment.

- Quality issues were identified in most of the processes and suggestions to improve them were highlighted.
- The cost of quality was also calculated for the top centre castings and brake shoe holders. This was done so as to create a system that can be used to calculate the costs that business incurs as a result of poor quality products being produced. The components of the cost of quality that were analysed include; prevention, appraisal, internal and external costs.
- The impact of defects on productivity was quantified.
- Quality defects that result from all the processes were analysed and the root cause analysis was conducted.
- Non-compliance reports received from unsatisfied customers were analysed. Other non-conformities that were received from external auditors were noted as areas of consideration for further improvement.
- Qualifound framework can be used as an improvement tool to improve the quality issues at the Transnet Foundry.
- In sand preparation, process capability indicated that the moulding machines 5,10 and 25 ton need to be calibrated and a failure mode effect analysis should be conducted.
- Process capability studies indicate that in mould hardness of green sand the process is out of control and as a result the mould hardness cannot be ascertained and this causes quality issues to arise.
- In melting the root cause analysis indicated that non-compliant scrap metal causes defects to occur.
- Measuring equipment such as the go/no-go gauges should be used to reduce dimensional defects on castings.

9. RECOMMENDATIONS & FUTURE WORK

9.1 RECOMMENDATIONS

- Appointment of quality controllers who will be responsible for ensuring that all the proposed improvements are implemented.
- Quality training workshops for all employees in the Foundry business.
- Top management to be taught about the effect of the cost of quality on the profitability of business.
- Transnet Engineering should measure quality as a key performance indicator for operators on the production line.
- Machines in the chemically bonded sand area should be investigated to check for failures and if possible they should be re-calibrated.
- The heat treatment machine should be calibrated and checked for failures.
- Quality should be treated as a culture and all of the Foundry employees should be involved in quality planning to help reduce the number of defects.
- A quality plan for suppliers should be established, to safeguard the quality of incoming raw materials.

9.2 FUTURE WORK

- A simulation study using a discrete event simulation software should be undertaken to investigate the quality issues
- A study into the cost of implementing a consolidated quality system in the Foundry versus the cost of poor quality
- A study into South African Foundries quality systems and their alignment with world class practises.
- Effectiveness of Qualifound and Foundry Total Failure Mode Effect Analysis as quality improvement frameworks

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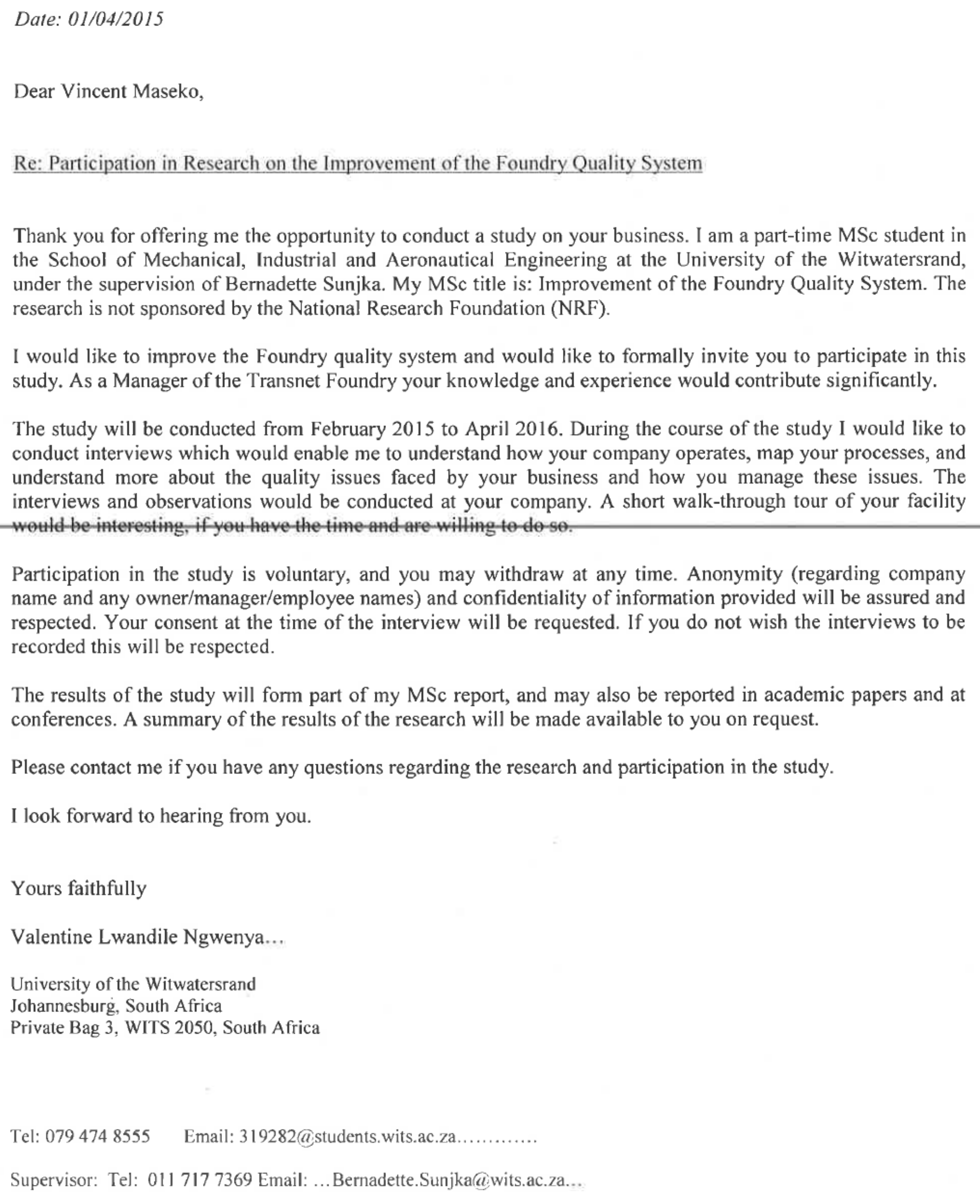
11. CONSENT

11.1 Company Consent



Date: 01/04/2015

Dear Vincent Maseko,

Re: Participation in Research on the Improvement of the Foundry Quality System

Thank you for offering me the opportunity to conduct a study on your business. I am a part-time MSc student in the School of Mechanical, Industrial and Aeronautical Engineering at the University of the Witwatersrand, under the supervision of Bernadette Sunjka. My MSc title is: Improvement of the Foundry Quality System. The research is not sponsored by the National Research Foundation (NRF).

I would like to improve the Foundry quality system and would like to formally invite you to participate in this study. As a Manager of the Transnet Foundry your knowledge and experience would contribute significantly.

The study will be conducted from February 2015 to April 2016. During the course of the study I would like to conduct interviews which would enable me to understand how your company operates, map your processes, and understand more about the quality issues faced by your business and how you manage these issues. The interviews and observations would be conducted at your company. A short walk-through tour of your facility would be interesting, if you have the time and are willing to do so.

Participation in the study is voluntary, and you may withdraw at any time. Anonymity (regarding company name and any owner/manager/employee names) and confidentiality of information provided will be assured and respected. Your consent at the time of the interview will be requested. If you do not wish the interviews to be recorded this will be respected.

The results of the study will form part of my MSc report, and may also be reported in academic papers and at conferences. A summary of the results of the research will be made available to you on request.

Please contact me if you have any questions regarding the research and participation in the study.

I look forward to hearing from you.

Yours faithfully

Valentine Lwandile Ngwenya…

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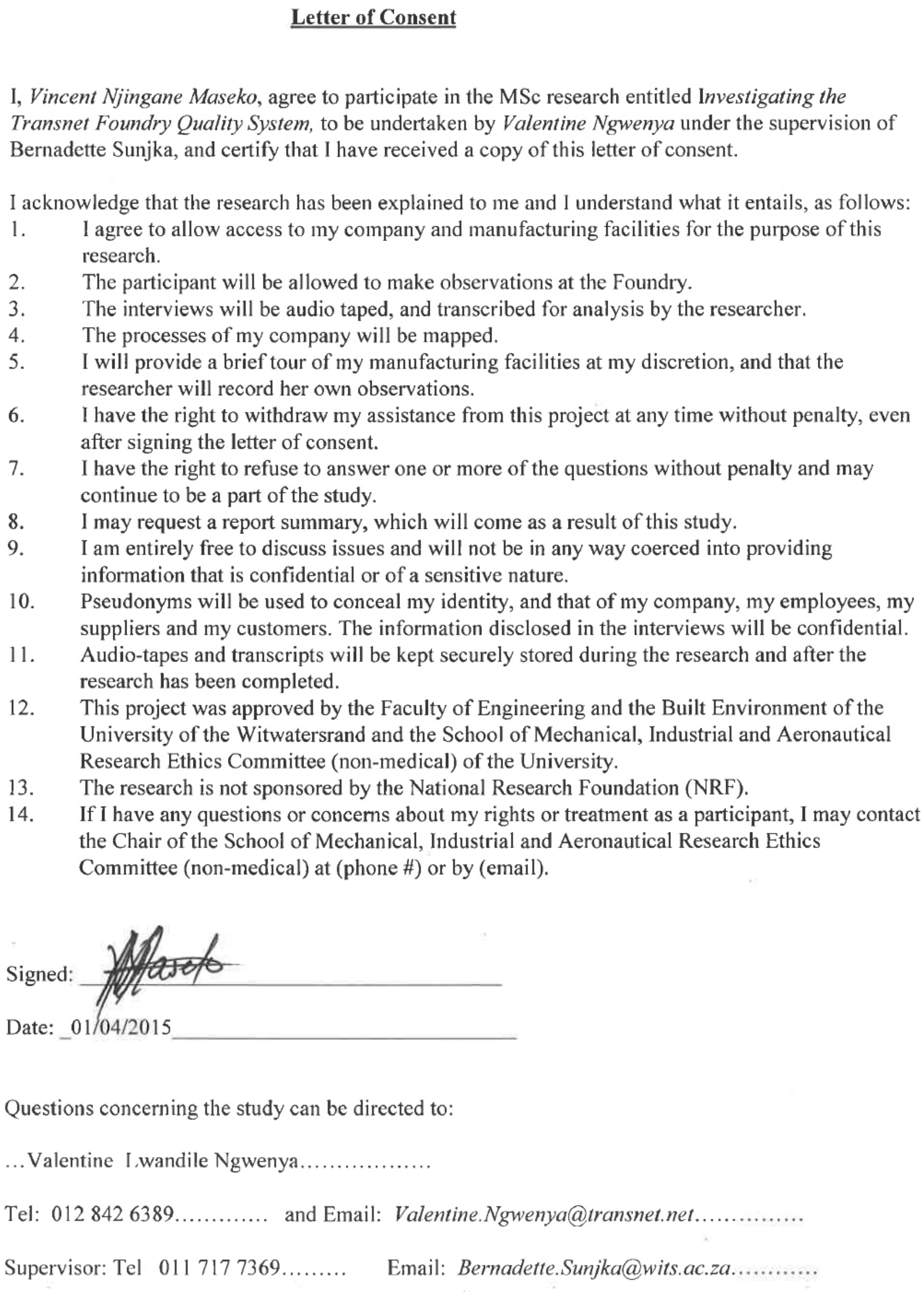


Letter of Consent

I, *Vincent Njingane Maseko*, agree to participate in the MSc research entitled I*nvestigating the Transnet Foundry Quality System,* to be undertaken by *Valentine Ngwenya* under the supervision of Bernadette Sunjka, and certify that I have received a copy of this letter of consent.

I acknowledge that the research has been explained to me and I understand what it entails, as follows:

1. I agree to allow access to my company and manufacturing facilities for the purpose of this research.
2. The participant will be allowed to make observations at the Foundry.
3. The interviews will be audio taped, and transcribed for analysis by the researcher.
4. The processes of my company will be mapped.
5. I will provide a brief tour of my manufacturing facilities at my discretion, and that the researcher will record her own observations.
6. I have the right to withdraw my assistance from this project at any time without penalty, even after signing the letter of consent.
7. I have the right to refuse to answer one or more of the questions without penalty and may continue to be a part of the study.
8. I may request a report summary, which will come as a result of this study.
9. I am entirely free to discuss issues and will not be in any way coerced into providing information that is confidential or of a sensitive nature.
10. Pseudonyms will be used to conceal my identity, and that of my company, my employees, my suppliers and my customers. The information disclosed in the interviews will be confidential.
11. Audio-tapes and transcripts will be kept securely stored during the research and after the research has been completed.
12. This project was approved by the Faculty of Engineering and the Built Environment of the University of the Witwatersrand and the School of Mechanical, Industrial and Aeronautical Research Ethics Committee (non-medical) of the University.
13. The research is not sponsored by the National Research Foundation (NRF).
14. If I have any questions or concerns about my rights or treatment as a participant, I may contact the Chair of the School of Mechanical, Industrial and Aeronautical Research Ethics Committee (non-medical) at (phone #) or by (email).

Signed: ______________________________

Date: _01/04/2015______________________

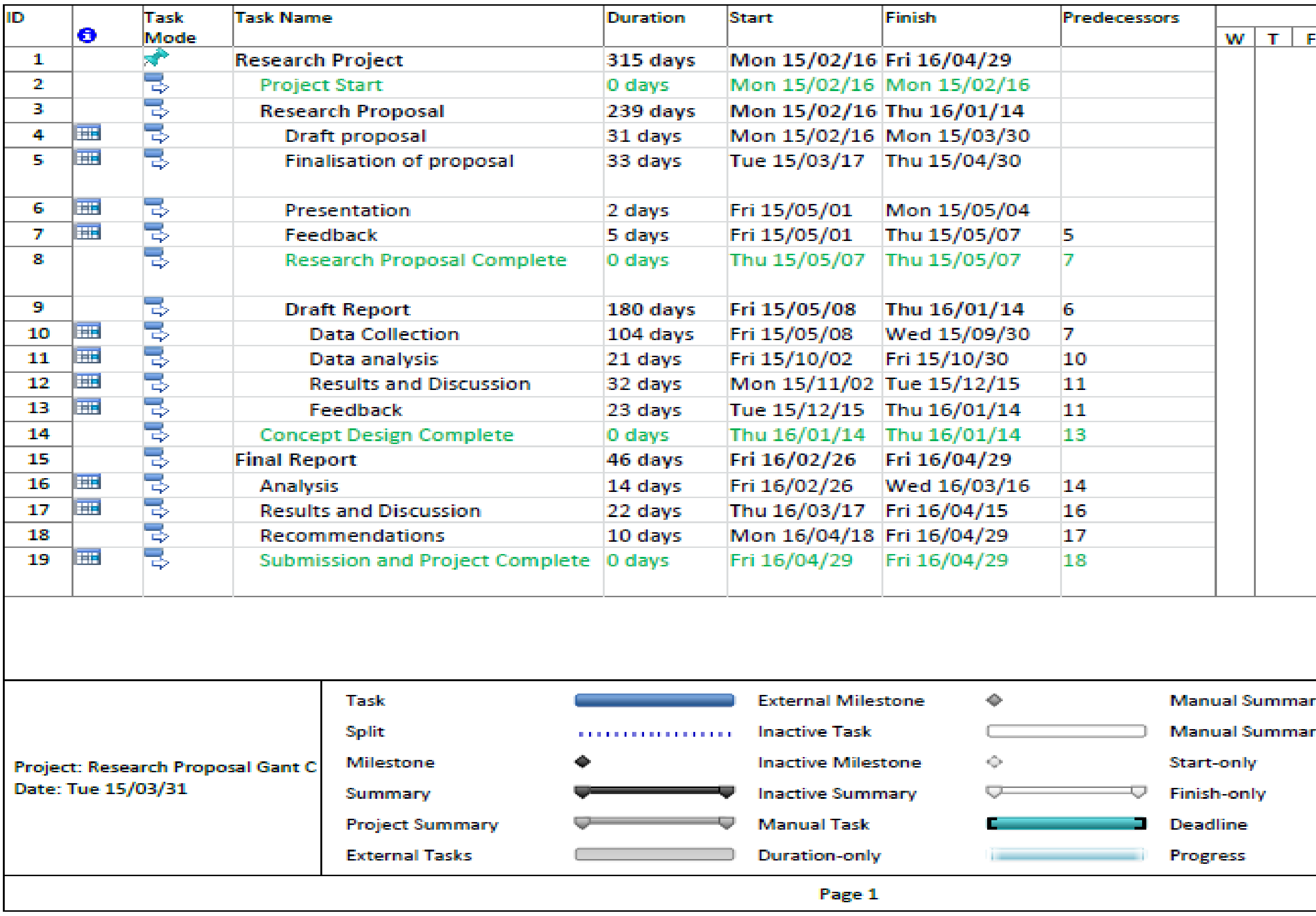
Questions concerning the study can be directed to:

…Valentine Lwandile Ngwenya………………

Tel: 012 842 6389………… and Email: *Valentine.Ngwenya@transnet.net*……………

Supervisor: Tel 011 717 7369……… Email: *Bernadette.Sunjka@wits.ac.za*…………

11.2 Research project timeline



ID	ℹ	Task Mode	Task Name	Duration	Start	Finish	Predecessors	W	T	F
1		📌	Research Project	315 days	Mon 15/02/16	Fri 16/04/29				
2		⇨	Project Start	0 days	Mon 15/02/16	Mon 15/02/16				
3		⇨	Research Proposal	239 days	Mon 15/02/16	Thu 16/01/14				
4	▦	⇨	Draft proposal	31 days	Mon 15/02/16	Mon 15/03/30				
5	▦	⇨	Finalisation of proposal	33 days	Tue 15/03/17	Thu 15/04/30				
6	▦	⇨	Presentation	2 days	Fri 15/05/01	Mon 15/05/04				
7	▦	⇨	Feedback	5 days	Fri 15/05/01	Thu 15/05/07	5			
8		⇨	Research Proposal Complete	0 days	Thu 15/05/07	Thu 15/05/07	7			
9		⇨	Draft Report	180 days	Fri 15/05/08	Thu 16/01/14	6			
10	▦	⇨	Data Collection	104 days	Fri 15/05/08	Wed 15/09/30	7			
11	▦	⇨	Data analysis	21 days	Fri 15/10/02	Fri 15/10/30	10			
12	▦	⇨	Results and Discussion	32 days	Mon 15/11/02	Tue 15/12/15	11			
13	▦	⇨	Feedback	23 days	Tue 15/12/15	Thu 16/01/14	11			
14		⇨	Concept Design Complete	0 days	Thu 16/01/14	Thu 16/01/14	13			
15		⇨	Final Report	46 days	Fri 16/02/26	Fri 16/04/29				
16	▦	⇨	Analysis	14 days	Fri 16/02/26	Wed 16/03/16	14			
17	▦	⇨	Results and Discussion	22 days	Thu 16/03/17	Fri 16/04/15	16			
18		⇨	Recommendations	10 days	Mon 16/04/18	Fri 16/04/29	17			
19	▦	⇨	Submission and Project Complete	0 days	Fri 16/04/29	Fri 16/04/29	18			

Project: Research Proposal Gant C
Date: Tue 15/03/31

Task	▬	External Milestone	◆	Manual Summar
Split	┄	Inactive Task	▭	Manual Summar
Milestone	◆	Inactive Milestone	◇	Start-only
Summary	▬	Inactive Summary	▭	Finish-only
Project Summary	▬	Manual Task	▬	Deadline
External Tasks	▬	Duration-only	▬	Progress

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Figure 11-1: research Project timeline

12. APPENDICES

12.1 Return sand Observations

Table 12-1: Return Sand Observations

Date	Shift	AFS	AFS Spec (50-60)	Fines%	Fine Content-2% Max
15/01/2015	Day	41.82	FALSE	0.92	TRUE
22/01/2015	Night	45	FALSE	0.66	TRUE
23/01/2015	Day	44.75	FALSE	56	TRUE
26/01/2015	Day	44.1	FALSE	0.96	TRUE
02/02/2015	Day	44.57	FALSE	0.59	TRUE
06/02/2015	Night	38.4	FALSE	0.53	TRUE
09/02/2015	Night	44.06	FALSE	3.42	FALSE
09/02/2015	Day	39.63	FALSE	1.66	TRUE
16/02/2015	Day	41.54	FALSE	3.05	FALSE
03/03/2015	Night	45.34	FALSE	3.41	FALSE
04/03/2015	Night	43.62	FALSE	3.49	FALSE
05/03/2015	Night	35.09	FALSE	0.99	TRUE
06/03/2015	Night	44.91	FALSE	2.19	FALSE
15/04/2015	Day	40.43	FALSE	2.16	FALSE
16/04/2015	Day	51.75	TRUE	6.89	FALSE
22/04/2015	Day	46.49	FALSE	3.57	FALSE
04/05/2015	Day	47.14	FALSE	3.37	FALSE
18/05/2015	Day	56.32	TRUE	8.29	FALSE
21/05/2015	Day	59.68	TRUE	10.81	FALSE
22/05/2015	Night	51.28	TRUE	4.72	FALSE
09/06/2015	Day	49	FALSE	4.55	FALSE
15/06/2015	Night	44.06	FALSE	1.42	TRUE
17/06/2015	Night	52.32	TRUE	9.53	FALSE
18/06/2015	Day	58.38	TRUE	9.89	FALSE

12.2 Return sand data

Table 12-2: Return sand data

Date	1700	850	600	425	300	212	150	106	75	53	Pan	AFS	Fines
15/01/2015	1.86	4.61	8.9	17.91	36.5	16.01	10.44	2.57	0.63	0.23	0.06	41.82	0.92
22/01/2015 NIGHT	0.68	1.39	4.47	14.34	44.02	19.48	12.17	2.53	0.43	0.17	0.06	45	0.66
23/01/2015	0.7	1.49	4.5	15.44	43.03	19.58	12.07	2.63	0.33	0.2	0.03	44.75	56
26/01/2015	1.52	2.58	6.37	16.75	38.41	18.25	11.53	3.14	0.68	0.24	0.04	44.1	0.96
02/02/2015	0.85	1.42	5.47	15.76	41.26	19.65	11.77	8.01	0.47	0.12	0	44.57	0.59
06/02/2015 NIGHT	3.1	4.2	10.43	21.72	37.63	12.83	7.2	1.54	0.37	0.13	0.03	38.4	0.53
09/02/2015 NIGHT	1.62	2.52	6.5	17.02	40.43	18.73	9	0.31	3.16	0.22	0.04	44.06	3.42
09/02/2015	1.45	2.56	6.99	16.71	40.54	17.46	10.04	1.74	1.27	0.27	0.12	39.63	1.66
16/02/2015	3.17	2.77	7.41	18.37	38.21	16.46	9.96	2.39	0.55	0.11	0	41.54	3.05
03/03/2015 NIGHT	4.11	4.09	8.29	15.98	33.08	16.56	10.23	4.09	2.44	0.89	0.08	45.34	3.41
04/03/2015 NIGHT	1.61	3.04	7.43	17.7	42.17	14.54	9.64	0.33	3.13	0.26	0.1	43.62	3.49
05/03/2015 NIGHT	3.15	7.66	16.65	24.04	32.59	8.73	4.49	1.32	0.66	0.28	0.05	35.09	0.99
06/03/2015 NIGHT	1.86	2.54	5.57	16.52	43.34	14.08	10.34	3.38	1.67	0.47	0.05	44.91	2.19
15/04/2015	8.19	5.73	8.76	16.48	32.53	13.77	9.62	2.53	1.58	0.45	0.13	40.43	2.16
16/04/2015	3.06	4.64	6.93	11.5	29.03	16.04	14	2.78	4.63	1.83	0.43	51.75	6.89
22/04/2015	3.31	2.76	6.22	15.7	36.76	16.34	11.65	3.49	2.87	0.63	0.07	46.49	3.57
04/05/2015	1.98	2.73	6.62	15.64	35.81	18.93	10.93	3.7	2.47	0.73	0.17	47.14	3.37
18/05/2015	1.07	1.25	2.65	9.4	33.45	24.17	16.43	3.12	6.98	1.09	0.22	56.32	8.29
21/05/2015	0.92	0.89	1.97	6.58	33.27	23.3	21.53	0.71	9.4	0.96	0.45	59.68	10.81
22/05/2015 NIGHT	1.79	1.14	3.34	10.93	38.61	20.92	14.77	3.32	3.82	0.71	0.19	51.28	4.72
09/06/2015	0.81	1.31	5.17	14.41	39.03	20	11.92	2.42	3.94	0.45	0.16	49	4.55
15/06/2015 NIGHT	1.7	2.46	6.67	16.7	40.06	16.72	10.38	3.23	1.1	0.28	0.04	44.06	1.42
17/06/2015 NIGHT	0.68	0.71	2.86	10.47	35.73	20.1	18.1	0.83	8.49	0.85	0.19	52.32	9.53
18/06/2015	0.98	0.51	1.96	11.45	36.75	19.75	12.06	6.87	8.65	1.05	0.19	58.38	9.89

12.3 New sand observations

Table 12-3: New sand checked against a specification

Date Tested	Pan	AFS	AFS Spec(45-55)	Fines	Fineness Spec 2% Max
16/01/2015 Cert 01	0	48.32	FALSE	3.17	FALSE
16/01/2015 Cert 02	0.01	48.34	FALSE	1.73	FALSE
16/01/2015 Cert 03	0.02	49.51	FALSE	2.29	FALSE
16/01/2015 Cert 04	0	48.78	FALSE	1.06	FALSE
27/01/2015 Cert 07	0	46.77	FALSE	0.61	TRUE
28/01/2015 Cert 08	0.02	48.66	FALSE	4.37	FALSE
02/02/2015 Cert 09	0.01	44.88	FALSE	1.35	FALSE
03/02/2015 Cert 10	0.03	44.68	FALSE	0.77	TRUE
09/02/2015 Cert 11	0.01	48.05	FALSE	2.08	FALSE
13/02/2015 Cert 12	0.01	47.96	FALSE	1.69	FALSE
21/02/2015 Cert 14	0.04	46.78	FALSE	2.36	FALSE
25/02/2015 Cert 16	0.02	46.06	FALSE	0.8	TRUE
03/03/2015 Cert 17	0.01	45.83	FALSE	0.61	TRUE
04/03/2015 Cert 18	0.06	46.33	FALSE	0.77	TRUE
11/03/2015 Cert 19	0.02	43.26	FALSE	2.27	FALSE
11/03/2015 Cert 20	0.01	40.98	FALSE	1.6	FALSE
26/03/2015 Cert 21	0.01	51.81	TRUE	5.2	FALSE
14/04/2014 Cert 22	0.02	47.32	FALSE	4.16	FALSE
20/04/2015 Cert 23	0.02	49.42	FALSE	5.24	FALSE
24/04/2015 Cert 24	0.05	44.28	FALSE	5.23	FALSE
24/04/2015 Cert 25	0.05	49.66	FALSE	1.31	FALSE

13/05/2015 Cert 29	0.01	48.35	FALSE	0.71	TRUE
14/05/2015 Cert 30	0.02	48.35	FALSE	0.77	TRUE
18/05/2015 Cert 31	0.01	47.47	FALSE	0.68	TRUE
22/05/2015 Cert 32	0.02	46.77	FALSE	0.62	TRUE
22/05/2015 Cert 33	0.03	48.7	FALSE	5.43	FALSE
22/05/2015 Cert 34	0.05	47.18	FALSE	0.71	TRUE
4/06/2015 Cert 35	0.04	48.74	FALSE	0.81	TRUE
4/06/2015 Cert 37	0.03	48.53	FALSE	1.88	FALSE
09/06/2015 Cert 38	0.01	47.01	FALSE	4.13	FALSE
08/06/2015 Cert 39	0	41.97	FALSE	2.08	FALSE
11/06/2015 Cert 40	0.04	52.92	TRUE	7.22	FALSE
11/06/2015 Cert 41	0.02	51.35	TRUE	6.75	FALSE
19/06/2015 Cert 42	0.05	50.55	TRUE	6.69	FALSE
19/06/2015 Cert 43	0.02	51.3	TRUE	4.18	FALSE
19/06/2015 Cert 44	0.05	47.7	FALSE	2.47	FALSE
22/05/2015 Cert 45	0.02	49.58	FALSE	4.71	FALSE
29/06/2015 Cert 48	0	48.14	FALSE	1.8	FALSE
01/07/2015 Cert 49	0	46.97	FALSE	1.63	FALSE
06/07/2015 Cert 50	0.01	40.87	FALSE	1.08	FALSE

New sand data observations

Table 12-4 : New sand data observations

Date Tested	1700	850	600	425	300	212	150	106	75	53	Pan	AFS	Fines
16/01/2015 Cert 01	0	0.22	1.64	12.07	49.03	19.64	12.61	1.56	3.07	0.1	0	48.32	3.17
16/01/2015 Cert 02	0	0.39	4.71	15.09	33.31	26.85	15.65	2.38	1.67	0.05	0.01	48.34	1.73
16/01/2015 Cert 03	0	0.21	1.41	11.17	44.52	22.2	15.22	3	2.16	0.11	0.02	49.51	2.29
16/01/2015 Cert 04	0.02	0.13	1.15	12.04	45.91	20.37	14.93	4.35	0.95	0.11	0	48.78	1.06
27/01/2015 Cert 07	0.01	1.13	1.54	13.33	47.08	20.67	12.89	3.73	0.54	0.07	0	46.77	0.61
28/01/2015 Cert 08	0.01	0.08	1.3	12.7	49.69	19.96	11.29	0.5	4.13	0.22	0.02	48.66	4.37
02/02/2015 Cert 09	0	0.27	2.76	15.6	51.23	15.83	10.41	1.48	1.24	0.1	0.01	44.88	1.35
03/02/2015 Cert 10	0	0.14	2.83	16	51.3	16.98	9.56	2.42	0.65	0.09	0.03	44.68	0.77
09/02/2015 Cert 11	0	0.17	1.51	13.5	47.76	19.2	12.75	3.03	1.9	0.17	0.01	48.05	2.08
13/02/2015 Cert 12	0	0.39	2.9	14.16	44.91	18.32	13.57	3.81	1.41	0.27	0.01	47.96	1.69
21/02/2015 Cert 14	0	0.01	0.85	13.39	53.91	17.33	10.69	1.46	2.16	0.16	0.04	46.78	2.36
25/02/2015 Cert 16	0	0.26	1.57	14.99	50.16	17.75	11.42	3.06	0.66	0.12	0.02	46.06	0.8
03/03/2015 Cert 17	0	0.34	1.82	12.76	50.54	20.01	11.56	2.44	0.57	0.03	0.01	45.83	0.61
04/03/2015 Cert 18	0	0.2	1.73	12.22	51.4	19.01	12.04	2.56	0.63	0.08	0.06	46.33	0.77
11/03/2015 Cert 19	0.03	0.05	5.38	22.72	46.47	14.16	8.35	0.72	2.12	0.13	0.02	43.26	2.27
11/03/2015 Cert 20	0	1.19	4.81	25.58	48.16	11.94	6.51	0.13	1.56	0.03	0.01	40.98	1.6
26/03/2015 Cert 21	0	0.56	2.62	11.45	41.13	21.26	15.8	1.94	4.96	0.23	0.01	51.81	5.2

14/04/2014 Cert 22	0	0.78	3.82	14.81	44.7	19.56	12.34	0.31	3.98	0.16	0.02	47.32	4.16
20/04/2015 Cert 23	0.01	0.87	3.78	13.23	41.65	21.14	13.92	0.17	5.05	0.17	0.02	49.42	5.24
24/04/2015 Cert 24	0.02	0.67	2.53	10.66	43.41	20.93	15.65	0.83	4.93	0.25	0.05	44.28	5.23
24/04/2015 Cert 25	0	1.2	3.71	11.59	39.76	20.15	18.01	5.14	1.07	0.19	0.05	49.66	1.31
13/05/2015 Cert 29	0	0.45	3.33	16.55	0.85	30.48	13.72	4.82	0.68	0.02	0.01	48.35	0.71
14/05/2015 Cert 30	0	0.35	3.65	17.12	30.58	29.06	13.34	5.14	0.72	0.03	0.02	48.35	0.77
18/05/2015 Cert 31	0	0.49	3.91	17.35	31.65	28.72	12.58	4.63	0.64	0.03	0.01	47.47	0.68
22/05/2015 Cert 32	0	0.59	4.31	18.25	32.15	27.95	11.87	4.28	0.42	0.18	0.02	46.77	0.62
22/05/2015 Cert 33	0	0.37	2.69	17.96	44.76	17.35	11.23	0.83	5.2	0.2	0.03	48.7	5.43
22/05/2015 Cert 34	0	0.39	6.21	14.78	33.72	27.58	11.95	4.57	0.44	0.22	0.05	47.18	0.71
4/06/2015 Cert 35	0	0.35	3.15	16.15	30.65	30.42	13.35	5.13	0.62	0.15	0.04	48.74	0.81
4/06/2015 Cert 37	0	0.25	4.2	15.15	32.85	27.55	15.35	2.74	1.8	0.05	0.03	48.53	1.88
09/06/2015 Cert 38	0	0.76	4.09	18.14	42.05	18.19	12.38	0.26	4.06	0.06	0.01	47.01	4.13
08/06/2015 Cert 39	0.03	0.73	5.98	24.86	45.8	12.07	7.96	0.32	2.05	0.03	0	41.97	2.08
11/06/2015 Cert 40	0	0.24	2.58	14.07	41.13	17.98	14.92	1.87	6.78	0.4	0.04	52.92	7.22
11/06/2015 Cert 41	0	0.35	2.72	14.02	44.99	16.55	13.08	1.14	6.21	0.52	0.02	51.35	6.75
19/06/2015 Cert 42	0	0.75	4.03	15.02	42.36	17.75	12.54	0.78	6.14	0.5	0.05	50.55	6.69
19/06/2015 Cert 43	0.01	0.8	2.76	14.62	39.4	18.47	15.38	4.39	3.64	0.52	0.02	51.3	4.18
19/06/2015 Cert 44	0.01	1.14	4.49	15.89	42.03	17.32	13.11	3.64	2.16	0.26	0.05	47.7	2.47
22/05/2015 Cert 45	0.01	0.69	2.75	12.11	44.99	19.68	14.15	0.89	4.56	0.13	0.02	49.58	4.71
29/06/2015 Cert 48	0.04	0.26	4.46	16.54	31.12	27.88	15.31	2.58	1.72	0.08	0	48.14	1.8
01/07/2015 Cert 49	0	0.72	5.28	15.45	34.25	26.41	14.19	2.07	1.61	0.02	0	46.97	1.63

06/07/2015 Cert 50	0	1.58	7.84	22.51	46.01	12.98	7.17	0.89	1.03	0.04	0.01	40.87	1.08

12.4 Green sand properties

The green sand properties for the period that the observations were conducted can be seen in Table 12-5.

Table 12-5: Green sand properties observations

Date: Time	%Moist (2.5%)	Compactability (45-52%)	Compression Strength	Perm (80-110)	Green Shear Strength (10-15psi)
14/01/2015 21H00	3.4	60	6.9	140	5.5
14/01/2015 22H00	3.3	60	6.6	150	5.2
14/01/2015 23H00	3.2	61	6.8	190	5.3
14/01/2015 00H00	3.1	59	6.9	170	5.5
15/01/2015 09H50	3.1	56	6.6	200	5.2
15/01/2015 10H50	3.3	61	6.3	170	5
15/01/2015 11H50	3	57	6.7	170	5.3
15/01/2015 13H30	3.1	58	6.5	210	5.1
16/01/2015 21H00	3.3	60	6.8	160	5.3
16/01/2015 21H40	3.2	59	7	170	5.5
16/01/2015 22H20	2.7	55	7.9	200	6.2
21/01/2015 21H00	2.9	58	6.7	180	5.3
22/01/2015 19H20	2.8	50	7.4	210	5.8

22/01/2015 20H20	2.9	56	6.5	170	5.1
22/01/2015 21H50	3	58	6.4	170	5
22/01/2015 23H00	3	55	7.2	180	5.6
22/01/2015 00H00	3.5	61	6	150	4.6
22/01/2015 01H00	3	60	6.1	165	4.7
22/01/2015 02H00	3.5	61	5.4	140	4.2
23/01/2015 08H00	3.3	58	6.8	160	5.3
23/10/2015 09H00	2.2	43	9.3	190	7.3
23/01/2015 10H00	3.1	53	7.1	180	5.5
23/01/2015 11H30	2.7	48	7.3	170	5.7
23/01/2015 13H25	2.5	44	8.4	195	6.6
26/01/2015 11H50	3	51	7.3	200	5.7
26/01/2015 13H40	3.4	60	5.1	160	4
26/01/2015 14H40	3.1	58	6.5	180	5.1
27/01/2015 21H30	2.8	52	7.5	160	5.9
27/01/2015 01H45	2.8	52	7.7	170	6
28/01/2015 09H45	3.1	59	6.2	195	4.8
28/01/2015 10H45	2.5	55	7.6	200	6
28/01/2015 11H45	2.7	58	6.8	200	5.3
28/01/2015 13H35	2.7	56	7.2	190	5.7
29/01/2015 10H45	3	59	6.9	200	5.4
29/01/2015 11H45	3.3	60	6	170	4.7

29/01/2015 13H40	3.2	59	6.2	190	4.9
29/01/2015 14H40	3.1	60	6.1	210	4.7
29/01/2015 15H40	2.9	56	6.4	200	5
29/01/2015 16H30	3.6	62	5.9	170	4.6
02/02/2015 10h45	3.9	59	6	140	4.7
02/02/2015 11H20	3	57	6.9	150	5.4
02/02/2015 12H15	3.1	54	6.9	150	5.4
02/02/2015 13H30	2.7	55	7	170	5.5
02/02/2015 14H30	2.9	53	7.2	180	5.6
02/02/2015 15H30	2.9	55	8	180	6.3
02/02/2015 20H45	3.2	56	6	170	4.7
02/02/2015 21H45	3	58	6.5	160	5.1
02/02/2015 22H45	2.5	54	7.8	200	6.1
02/02/2015 23H45	3	58	7.3	190	5.7
02/02/2015 00H45	2.8	58	7.3	185	5.7
04/02/2015 11H00	2.8	55	7.2	180	5.7
04/02/2015 12H00	2.7	54	7	190	5.5
04/02/2015 13H30	2.6	51	8	190	6.3
04/02/2015 14H00	2.5	49	8.2	210	6.4
05/02/2015 22H50	2.7	55	7.6	230	6
05/02/2015	2.5	54	7.8	200	6.1
06/02/2015 20H35	2.5	56	8	190	6.3

06/02/2015 21H35	5.1	63	4.5	90	0
06/02/2015 22H35	2.8	57	7.5	210	5.8
06/02/2015 23H35	3.4	56	7	170	5.5
06/02/2015 00H35	2.1	50	9.2	210	7.2
06/02/2015 01H35	3	57	6.8	200	5.3
09/02/2015 19H30	2.9	54	7.9	175	6.2
09/02/2015 20H50	3	52	8.1	180	6.4
09/02/2015 21H30	2.6	50	7.6	190	6
09/02/2015 22H30	2.6	50	8.3	190	6.6
09/02/2015 13H20	3.2	60	6.3	160	4.9
09/02/2015 14H20	2.4	55	8	210	6.3
09/02/2015 15H20	3.1	58	6.6	160	5.2
09/02/2015 16H20	2.4	56	8	200	6.3
10/02/2015 09H45	3.2	61	6.4	180	5
10/02/2015 13H30	3.2	61	7	170	5.4
10/02/2015 14H30	2.6	56	7.5	200	5.9
10/02/2015 15H30	2.9	60	7.2	190	5.7
10/02/2015 16H30	2.6	61	7.8	190	5.8
11/02/2015 13H30	2.9	58	7	210	5.5
11/02/2015 14H30	3.3	63	6.6	150	5.1
11/02/2015 15H30	2.9	60	7.1	180	5.6
12/02/2015 22H30	2.5	42	8.8	210	6.9

12/02/2015 23H30	2.8	57	8	180	6.3
12/02/2015 00H30	2.2	37	9	230	7
19/02/2015 18H55	2.9	51	7.2	150	5.7
23/02/2015 22H00	2.8	42	8.5	150	6.6
23/02/2015 23H00	2.8	40	8.7	140	6.8
23/02/2015 00H10	3.3	51	7.9	170	6.1
23/02/2015 01H20	3.6	53	8	180	6.3
24/02/2015 10H40	3.3	59	6.1	140	4.7
24/02/2015 11H40	3.6	57	6.2	130	4.8
16/02/2015 11H15	2.5	49	8.4	230	6.6
16/02/2015 12H15	2.9	52	8	180	6.3
16/02/2015 13H30	3.3	60	6.9	170	5.4
16/02/2015 14H30	3	55	7.9	170	6.2
17/02/2015 11H10	2.9	48	7.8	165	6.1
17/02/2015 12H00	2.5	41	9	170	7
17/02/2015 13H40	2.8	45	8.3	160	6.5
18/02/2015 23H15	3.4	58	7	160	5.5
03/03/2015 21H40	3.8	58	6.4	140	5
03/03/2015 00H00	3.8	57	7.2	145	5.6
03/03/2015 01H40	3.8	58	6	150	4.7
03/03/2015 02H40	3.1	55	8.1	190	6.3
03/03/2015 14H00	3.9	54	8.3	135	6.5

04/03/2015 10H30	3.8	52	8.1	150	6.3
04/03/2015 11H10	3.3	51	9.3	145	7.3
04/03/2015 13H30	3.3	52	9	145	7
04/03/2015 21H15	3.7	55	7.4	150	5.8
04/03/2015 22H15	2.5	49	8.1	230	6.3
04/03/2015 23H15	3.2	57	7.2	200	5.6
04/03/2015 00H15	3	55	6.9	170	5.4
04/03/2015 02/15	2.9	52	7.4	190	5.8
05/03/2015 19H40	3.1	56	7	190	5.5
05/03/2015 21H00	4.3	61	6	140	5.1
05/03/2015 22H15	3	52	7.8	210	6.1
05/03/2015 01H20	3.4	58	7.3	150	5.7
05/03/2015 02H15	2.8	50	8	200	6.2
06/03/2015 22H15	3.5	60	6.1	170	4.7
06/03/2015 23H15	3.1	52	6.6	210	5.1
06/03/2015 00H15	3.8	61	7	140	5.5
06/03/2015 01H15	3.6	59	7.1	145	5.6
09/03/2015 20H50	4	51	8	140	6.3
09/03/2015 21H50	4.2	53	7.8	130	6.1
09/03/2015 23H20	4.5	60	6.9	120	5.4
11/03/2015 19H30	3.3	51	8.1	135	6.3
11/03/2015 20H30	3.1	47	9	170	7

11/03/2015 21H15	3	45	10.3	150	8.1
11/03/2015 22H20	2.9	43	9.7	160	7.6
11/03/2015 00H10	3.3	50	8	150	6.3
16/03/2015 22H00	2.8	42	8.2	180	6.4
16/03/2015 01H50	3.6	57	7.5	130	5.8
16/03/2015 02H30	4.3	61	6.2	140	4.8
17/03/2015 21H00	4.4	61	5.6	120	4.4
17/03/2015 22H00	3.3	58	6.9	150	5.3
17/03/2015 23H00	4.8	62	6.2	90	4.8
17/03/2015 02H00	5.7	57	6.9	120	5.7
18/03/2015 21h20	3.7	55	7	160	5.5
18/03/2015 22H20	3.1	55	8.2	180	6.5
18/03/2015 01H20	3.2	58	7.9	150	6.2
02/04/2015 09H50	3	47	8.6	160	6.8
02/04/2015 10H50	2.8	40	9.9	190	7.8
07/04/2015 10H00	3.4	57	7.3	140	5.7
07/04/2015 11H00	3.5	57	6.9	140	5.4
07/04/2015 12H00	3.6	54	7	145	6.3
07/04/2015 13H30	3.5	55	7.7	150	6
08/04/2015 08H45	3	46	7.5	180	5.8
08/04/2015 10H16	3.4	57	6.3	180	4.7
08/04/2015 11H20	3	50	7.3	230	5.7

08/04/2015 13H40	2.8	46	6.3	200	6.6
09/04/2015 08H40	3.2	53	8	190	6.3
09/04/2015 10H00	3.3	52	7.9	200	6.2
09/04/2015 11H00	3.1	49	8.5	210	6.7
09/04/2015 12H10	3.2	47	8.2	150	6.4
09/04/2015 13H30	3.9	57	6.9	140	5.4
10/04/2015 09H45	3.5	56	7.1	200	5.6
10/04/2015 10H45	3.3	55	7.5	190	5.8
10/04/2015 11H45	3	59	6.8	140	5.4
14/04/2015 11H00	3.5	58	6.8	170	5.3
15/04/2015 09H40	3.4	56	7.3	210	5.8
15/04/2015 10H45	3.1	55	8.1	180	6.3
16/04/2015 08H30	3.2	55	7.4	170	5.8
16/04/2015 09H30	3.4	56	7.8	200	6.1
16/04/2015 10H30	3.4	55	7.4	180	5.9
16/04/2015 11H30	3.2	57	7.4	200	5.8
17/04/2015 10H20	3.2	50	8.1	165	6.3
17/04/2015 11H20	3.2	54	8.2	155	6.4
17/04/2015 12H15	3.3	55	8.1	150	6.3
17/04/2015 13H30	3.8	57	7.2	145	5.6
21/04/2015 10H20	3.1	42	9.2	200	7.2
21/04/2015 11H30	3.4	53	8.2	180	6.4

22/04/2015 09H55	3.3	51	8.2	240	6.5
22/04/2015 10H55	3.4	56	7.6	200	5.9
22/04/2015 14H55	3.6	57	7.8	200	6.1
23/04/2015 08H30	3.3	53	7.4	190	5.8
23/04/2015 09H45	3.2	50	8.2	180	6.5
23/04/2015 10H45	3	53	8	200	6.3
23/04/2015 11H45	2.8	50	8	200	6.3
05/05/2015 20H45	3.4	56	7.6	155	6
05/05/2015 21H45	2.6	46	8.8	180	6.9
06/05/2015 13H30	3.5	53	8.7	220	6.8
06/05/2015 14H20	3.4	52	9	230	7
06/05/2015 15H30	3.3	50	8.6	210	6.7
04/06/2015 08H00	3.3	57	7.6	160	6
04/06/2015 10H00	3.1	54	8.2	195	6.5
04/06/2015 11H40	3.1	55	8.1	170	6.2
04/06/2015 13H30	3.2	57	8	180	6.3
04/06/2015 14H30	3.4	58	7.8	170	6.1
09/06/2015 10H15	2.3	34	9.3	210	7.3
09/06/2015 11H15	3.2	59	7.3	190	5.7
09/06/2015 13H45	3.1	57	7.7	190	6.1
09/06/2015 15H40	3.1	54	7.6	180	6
10/06/2015 21H45	4	61	8	120	6.3

10/06/2015 22H45	4	59	7.5	130	5.9
10/06/2015 23H45	4.1	60	7.1	120	5.5
10/06/2015 10H45	2.9	50	7.8	180	6.1
10/06/2015 11H45	3.8	62	7.1	140	5.6
10/06/2015 16H45	3.3	59	7.4	145	5.8

12.5 Chemically bonded sand

Table 12-6: 5 ton machine observations

Date	Shift	AFS	AFS Spec (45-60)	Fines	Fines -Spec (3-5 sieves)
12/01/2015	Day	44.68	FALSE	1.37	FALSE
13/01/2015	Day	43.9	FALSE	1.03	FALSE
15/01/2015	Day	45.42	FALSE	0.88	FALSE
16/01/2015	Day	44.27	FALSE	1.39	FALSE
19/01/2015	Night	43.01	FALSE	0.97	FALSE
20/01/2015	Night	46.15	TRUE	1.07	FALSE
21/01/2015	Night	40.69	FALSE	0.24	FALSE
22/01/2015	Night	40.03	FALSE	0.4	FALSE
24/01/2015	Day	41	FALSE	2.3	FALSE
25/01/2015	Day	37.55	FALSE	1.19	FALSE
26/01/2015	Night	43.7	FALSE	0.62	FALSE
28/01/2015	Day	44.07	FALSE	1.38	FALSE
28/01/2015	Night	44.31	FALSE	0.53	FALSE
29/01/2015	Day	41.28	FALSE	1.18	FALSE
29/01/2015	Night	44.19	FALSE	1.35	FALSE
30/01/2015	Night	42.26	FALSE	0.47	FALSE
02/02/2015	Day	41	FALSE	0.93	FALSE
03/02/2015	Day	40.9	FALSE	0.81	FALSE
03/02/2015	Day	41.78	FALSE	0.58	FALSE
04/02/2015	Night	39.6	FALSE	0.36	FALSE
05/02/2015	Night	42.6	FALSE	0.38	FALSE
09/02/2015	Day	40.26	FALSE	1.08	FALSE
09/02/2015	Night	43.7	FALSE	1.44	FALSE
10/02/2015	Day	40.7	FALSE	0.96	FALSE
11/02/2015	Night	45.1	TRUE	1.48	FALSE
13/02/2015	Day	38.35	FALSE	0.11	FALSE
23/02/2015	Night	39.76	FALSE	0.68	FALSE
23/02/2015	Day	46.29	TRUE	1.96	FALSE
25/02/2015	Day	40.96	FALSE	0.29	FALSE

02/03/2015	Night	39.67	FALSE	0.34	FALSE
03/03/2015	Night	41.9	FALSE	2.45	FALSE
04/03/2015	Night	38.88	FALSE	0.47	FALSE
04/03/2015	Day	39.9	FALSE	0.5	FALSE
06/03/2015	Night	38.23	FALSE	0.25	FALSE
07/03/2015	Day	40.74	FALSE	1.44	FALSE
10/03/2015	Day	43.87	FALSE	3.46	TRUE
10/03/2015	Night	42.47	FALSE	0.45	FALSE
11/03/2015	Day	38.86	FALSE	0.16	FALSE
11/03/2015	Night	41.29	FALSE	0.56	FALSE
12/03/2015	Day	41.99	FALSE	1.04	FALSE
13/03/2015	Day	43	FALSE	1.62	FALSE
31/03/2015	Day	40.7	FALSE	1.08	FALSE
01/04/2015	Day	39.46	FALSE	0.65	FALSE
07/04/2015	Day	44.89	FALSE	3.42	TRUE
08/04/2015	Day	38.02	FALSE	0.34	FALSE
09/04/2015	Day	41..24	FALSE	2.7	FALSE
13/04/2015	Day	41.66	FALSE	1.19	FALSE
14/04/2015	Day	40.52	FALSE	0.9	FALSE
15/04/2015	Day	45.5	TRUE	4.19	TRUE
16/04/2015	Day	38.74	FALSE	1.59	FALSE
20/04/2015	Day	39.43	FALSE	1.17	FALSE
21/04/2015	Day	39.77	FALSE	1.85	FALSE
22/04/2015	Day	41.41	FALSE	1.31	FALSE
23/04/2015	Day	53.02	TRUE	9.76	FALSE
04/05/2015	Day	43.44	FALSE	2.93	FALSE
12/05/2015	Day	41.36	FALSE	1.14	FALSE
18/05/2015	Night	39.75	FALSE	1.24	FALSE
25/05/2015	Night	43.03	FALSE	1.36	FALSE
27/05/2015	Night	46.63	FALSE	2.51	FALSE
01/06/2015	Day	44.54	FALSE	4.56	TRUE
02/06/2015	Day	41.54	FALSE	2.1	FALSE
03/06/2015	Day	47.48	TRUE	4.93	TRUE

10 Ton Data collection

The data was collected from Foundry records for the 10 Ton machine (chemically bonded sand and the results can be seen in Table 12-7.

Table 12-7: Ten Ton Chemically bonded sand

Date	Shift	Pan	AFS	AFS - Spec(45-60)	Fines
20/01/2015	Day	0.13	45.89	TRUE	2.11
26/01/2015	Day	0.03	44.02	FALSE	0.6
04/02/2015	Day	0.03	44.45	FALSE	1.14
05/02/2015	Day	0.01	41.31	FALSE	0.67
06/02/2015	Day	0.01	42.1	FALSE	0.4
09/02/2015	Day	0.01	39.73	FALSE	0.43
23/02/2015	Day	0.02	42.05	FALSE	1.04
24/02/2015	Day	0.22	44.51	FALSE	4.72
12/02/2015	Day	0.01	41.3	FALSE	0.93
03/03/2015	Day	0.02	35.36	FALSE	1.53
04/03/2015	Day	0	35.73	FALSE	1.01
05/03/2015	Day	0.11	42.41	FALSE	3.35
05/03/2015	Night	0.03	33	FALSE	0.14
06/03/2015	Night	0.09	40.09	FALSE	1.08
07/03/2015	Day	0.01	41.95	FALSE	1.08
10/03/2015	Night	0.05	42.47	FALSE	1.57
11/03/2015	Night	0.04	42.1	FALSE	0.87
12/03/2015	Day	0.03	47.18	TRUE	2.11
13/04/2015	Day	0.03	40.77	FALSE	0.67
20/04/2015	Day	0.13	45.2	TRUE	7.38
20/04/2015	Day	0.13	47.72	TRUE	2.97
22/04/2015	Day	0.12	48.22	TRUE	3.12
29/04/2015	Day	0.01	37.77	FALSE	0.18
04/05/2015	Night	0.27	47.43	TRUE	6.15
04/05/2015	Day	0.55	53.64	TRUE	9.51
05/05/2015	Night	0.2	49.96	TRUE	6.76
05/05/2015	Day	0.59	57.94	TRUE	12.57
06/05/2015	Night	1.47	67.2	FALSE	17.85

07/05/2015	Day	0.29	60.77	FALSE	10.37
13/05/2015	Day	0.49	54.44	TRUE	12.53
14/05/2015	Night	0.16	56.56	TRUE	11.13
14/05/2015	Day	0.26	56.56	TRUE	12.08
27/05/2015	Day	0.06	42.07	FALSE	1.29
02/06/2015	Day	0.24	34.48	FALSE	1.72
03/06/2015	Day	0.1	38.11	FALSE	3.12
09/06/2015	Day	0.3	51.4	TRUE	6.23
10/06/2015	Day	0.06	40.16	FALSE	2.95
11/06/2015	Day	0.74	58.89	TRUE	13.12
12/06/2015	Day	0.67	48.85	TRUE	7.17
13/06/2015	Day	0.18	52.49	TRUE	8.6
14/06/2015	Day	0.01	48.53	TRUE	6.52
22/06/2015	Day	0.14	43.4	FALSE	6.2
23/06/2015	Day	0.4	55.08	TRUE	10.83
25/06/2015	Day	0.18	48.82	TRUE	4.39
01/07/2015	Day	0.1	46.26	TRUE	9.27
02/07/2015	Day	0.56	52.87	TRUE	10.71
03/07/2015	Day	0.02	36.78	FALSE	0.58
07/07/2015	Day	1.46	71.05	FALSE	15.6
08/07/2015	Day	0.32	43.96	FALSE	5.67
08/07/2015	Night	0.8	63.75	FALSE	11.87
09/07/2015	Day	0.12	42.78	FALSE	4.74

25 Ton Machine

For the 25 ton machine the data for chemically bonded sand can be seen in Table 12-8.

Table 12-8: Twenty five Ton chemically bonded sand

Date	Shift	Pan	AFS	AFS Spec (45-60)	Fines
16/01/2015	Night	0.03	46.49	TRUE	0.7

19/01/2015	Day	0.01	43.86	FALSE	0.91
19/01/2015	Night	0.01	40.81	FALSE	0.55
21/01/2015	Night	0.02	44.54	FALSE	0.47
21/01/2015	Day	0	40.08	FALSE	0.27
22/01/2015	Night	0.03	46.42	TRUE	1.28
24/01/2015	Day	0.1	47.01	TRUE	4.13
27/01/2015	Night	0.04	46.86	TRUE	0.29
28/01/2015	Day	0.01	40.8	FALSE	1.41
29/01/2015	Day	0	41.01	FALSE	0.81
29/01/2015	Night	0.05	44.54	FALSE	1.34
30/01/2015	Night	0.02	42.34	FALSE	0.27
03/02/2015	Night	0	41.79	FALSE	0.65
04/02/2015	Night	0.05	46.38	TRUE	1.58
05/02/2015	Day	0.05	45.21	TRUE	2.8
06/02/2015	Night	0.02	46.04	TRUE	4.07
09/02/2015	Night	0.05	44.04	FALSE	1.44
10/02/2015	Night	0.03	40.85	FALSE	0.98
11/02/2015	Day	0.01	41.72	FALSE	0.3
11/02/2015	Night	0.01	45.44	TRUE	0.92
12/02/2015	Night	0.01	42.09	FALSE	0.56
19/02/2015	Night	0.03	44.24	FALSE	3.8
20/02/2015	Day	0.09	39.81	FALSE	1.02
23/02/2015	Night	0.13	40.05	FALSE	0.99
24/02/2015	Day	0.02	40.86	FALSE	0.83
25/02/2015	Night	0.03	39.78	FALSE	0.6
02/03/2015	Day	0.05	42.99	FALSE	1.8
03/03/2015	Night	0.01	34.36	FALSE	0.22
04/03/2015	Night	0.03	40.57	FALSE	0.8
05/03/2015	Night	0.02	41.69	FALSE	1.37
07/03/2015	Day	0	39.1	FALSE	1.1
10/03/2015	Night	0.01	42.09	FALSE	0.65
10/03/2015	Day	0.09	40.17	FALSE	1.08
11/03/2015	Night	0.02	42	FALSE	1.41
12/03/2015	Day	0.01	45.87	TRUE	1.11
13./03/2015	Day	0.03	41.43	FALSE	1.96

07/04/2015	Day	0.02	39.75	FALSE	0.68
08/04/2015	Day	0.15	48.61	TRUE	5.2
09/04/2015	Day	0.02	39.45	FALSE	0.51
10/04/2015	Day	0.03	43.99	FALSE	0.86
13/04/2015	Day	0.02	43.58	FALSE	2.3
20/04/2015	Day	0.01	44.9	FALSE	2.61
21/04/2015	Day	0.27	48.69	TRUE	6.28
22/04/2015	Day	0.11	49.13	TRUE	3.57
29/04/2015	Day	1.05	54.35	TRUE	5.57
04/05/2015	Day	0.81	52.82	TRUE	6.55
05/05/2015	Night	0.03	33.73	FALSE	0.17
06/05/2015	Night	0.49	45.62	TRUE	4.9
07/05/2015	Day	0.04	52.57	TRUE	3.73
11/05/2015	Night	0.16	49.26	TRUE	5.97
12/05/2015	Day	0.03	45.88	TRUE	2.38
14/05/2015	Day	1.67	55.57	TRUE	6.32
14/05/2015	Night	1.07	61.45	FALSE	13.59
15/05/2015	Day	0.29	53.78	TRUE	7.16
15/05/2015	Night	0.02	49	TRUE	4.33
18/05/2015	Day	0.35	55.1	TRUE	7.22
18/05/2015	Night	0.07	45.66	TRUE	2.6
19/05/2015	Day	0.08	46.14	TRUE	2.5
20/05/2015	Night	0.1	45.37	TRUE	4.05
21/05/2015	Night	0.27	49.25	TRUE	5.45
21/05/2015	Day	0.07	46.72	TRUE	5.29
27/05/2015	Day	0.23	44.05	FALSE	1.6
01/06/2015	Day	0.29	44.71	FALSE	4.67
01/06/2015	Night	0.32	47.67	TRUE	6.45
02/06/2015	Day	0.83	53.97	TRUE	6.88
04/06/2015	Day	0.41	50.19	TRUE	3.61
10/06/2015	Day	0.23	49.35	TRUE	3.28
12/06/2015	Day	0.07	46.47	TRUE	1.95
19/06/2015	Night	0.26	48.68	TRUE	2.69
22/06/2015	Day	0	35.15	FALSE	0.25
23/06/2015	Day	0.13	60.86	FALSE	12.04

23/06/2015	Night	0.39	54.42	TRUE	9.83
24/06/2015	Night	0.07	46.85	TRUE	1.95
25/06/2015	Day	1.07	56.01	TRUE	5.94
30/06/2015	Day	0.02	46.06	TRUE	3.49
01/07/2015	Day	0.23	49.89	TRUE	7.48
06/07/2015	Night	0.98	60.42	FALSE	13.83
07/07/2015	Night	0.06	44.82	FALSE	2.94
08/07/2015	Day	0.09	46.26	TRUE	3.06
08/07/2015	Night	0.6	55.67	TRUE	7.88

The mixers (5, 10 and 25 ton machines) need regular calibration to ensure consistent mould and core quality.

12.5 Green sand mould hardness

Table 12-9 : Green sand mould hardness

Green Sand									
			Sample hardness						**Average**
Date	**Type**	**Number of moulds made**	**Specification (80-100)**						
08/05/2015	/17	160	91	87	90	88	86	89	89
	/18	160							
12/05/2015	/17	54	89	87	90	87	89	87	88
	/18	54	88	87	88	85	89	88	
13/05/2015	/17	52	91	88	86	89	87	89	88
	/18	52	88	86	90	88	87	87	88
14/05/2015	/17	90	87	91	88	90	88	87	89
	/18	90	90	87	91	88	91	87	89
18/05/2015	/17	160	90	87	86	88	87	89	88
	/18	160	88	90	88	86	88	87	88
21/05/2015	/17	132	90	87	89	86	89	87	88
	/18	132	88	91	87	90	88	89	89
23/05/2015	/17	160	88	91	87	89	88	90	89
	/18	160	90	87	91	88	86	89	89

27/05/2015	/17	68	90	87	90	88	86	89	88
	/18	68	88	87	90	87	91	88	89
01/06/2015	/17	98	90	87	91	88	87	89	89
	/18	98	88	87	89	91	87	89	89
02/06/2015	/17	160	91	87	89	88	89	86	88
	/18	160	90	87	89	88	89	86	88
03/06/2015	/17	60	91	87	90	88	87	89	89
	/18	60	88	91	87	89	86	90	89
10/06/2015	/17	120	91	87	89	87	86	90	88
10/06/2015	/18	120	86	91	88	90	86	89	88
11/06/2015	/17	60	90	87	89	88	86	90	88
	/18	60	88	87	88	90	89	86	88
12/06/2015	/17	76	88	89	87	90	88	90	89
	/18	76	87	89	86	90	88	87	88
12/06/2015	/17	80	89	87	90	87	89	87	88
	/18	80	89	86	91	88	86	88	88
11/08/2015	/17	50	87	89	86	90	88	87	88
	/18	50	88	87	90	87	91	88	89
17/08/2015	/17	51	88	91	87	90	88	89	89
	/18	51	88	91	87	89	88	90	89
27/08/2015	/17	56	88	91	87	90	88	89	89
	/18	56	88	91	87	89	88	90	89
31/08/2015	/17	30	86	91	88	90	86	89	88
	/18	30	90	87	86	88	87	89	88
01/09/2015	/17	112	87	90	89	86	88	87	88
	/18	112	91	87	90	86	88	86	88
02/09/2015	/17	100	87	91	88	86	89	88	88
	/18	100	87	91	86	90	89	87	88
03/09/2015	/17	106	90	87	90	88	86	89	88
	/18	106	88	91	87	89	86	90	89
07/09/2015	/17	64	90	87	89	88	89	86	88
	/18	64	91	87	90	88	87	89	89
21/09/2015	/17	60	87	91	88	86	89	88	88

	/18	60	86	91	88	90	86	89	88
29/09/2015	/17	112	89	88	90	88	91	87	89

12.6 Chemically bonded broken moulds

Table 12-10: Broken moulds data

Chemically bonded sand			
Date	**Casting type**	**Number of moulds made**	**Broken moulds**
07/05/2015	TCC	29	0
08/05/2015	TCC	30	1
11/05/2015	TCC	14	1
12/05/2015	TCC	29	1
13/05/2015	TCC	18	0
13/05/2015	TCC	28	2
14/05/2015	TCC	17	4
15/05/2015	TCC	20	0
15/05/2015	TCC	25	0
15/05/2015	TCC	23	1
18/05/2015	TCC	35	3
19/05/2015	TCC	5	1
25/05/2015	TCC	29	1
26/05/2015	TCC	10	2
27/05/2015	TCC	27	0
02/06/2015	TCC	13	2
03/06/2015	TCC	30	1
04/06/2015	TCC	35	0
05/06/2015	TCC	20	1
08/06/2015	TCC	35	1
09/06/2015	TCC	35	0

10/06/2015	TCC	16	0
11/06/2015	TCC	35	0
11/06/2015	TCC	30	1
12/06/2015	TCC	25	0
12/06/2015	TCC	35	0
13/06/2015	TCC	25	0
15/06/2015	TCC	25	1
22/06/2015	TCC	6	1
23/06/2015	TCC	30	1
24/06/2015	TCC	28	0
25/06/2015	TCC	11	0
26/06/2015	TCC	20	4
29/06/2015	TCC	24	0
30/06/2015	TCC	29	0
01/08/2015	TCC	24	0
05/08/2015	TCC	14	1
06/08/2015	TCC	14	1
07/08/2015	TCC	14	0
11/08/2015	TCC	11	0
13/07/2015	TCC	14	0
24/08/2015	TCC	8	0
25/08/2015	TCC	14	2
26/08/2015	TCC	6	0
30/08/2015	TCC	21	0
31/08/2015	TCC	21	1
01/09/2015	TCC	13	1
02/09/2015	TCC	15	0
04/09/2015	TCC	9	0
07/09/2015	TCC	14	0
08/09/2015	TCC	12	2
09/09/2015	TCC	14	1
10/09/2015	TCC	10	0

11/09/2015	TCC	14	0
14/09/2015	TCC	14	0
15/09/2015	TCC	12	0

12.7 Melting specification

The observations from the spectrometer lab can be seen in Table 12-11

Table 12-11: Melting data observation

Metals		**C**	**Mn**	**Si**	**S**	**P**	**Al**	**Ni**	**Cr**	**Cu**	**Sn**	**Mo**
Temperature	1700											
Specification	**Max**	0.35	1.8	0.6	0.05	0.05	0.06	0.2	0.3	0.4	0.07	N/A
	Min	0.25	1.4	0.4	0	0	0.03	0	0.2	0	0	0.2
	Max	0.28	1.5	0.5	0.04	0.04	0.05	0.15	0.3	0.25	0	0.3
Date												
01/06/2015		0.23	0.82	0.39	0.026	0.025	0.021	0.0081	0.055	0.065	0.013	0.14
02/06/2015		0.23	1.58	0.47	0.032	0.038	0.019	0.008	0.25	0.069	0.015	0.3
05/06/2015		0.2	0.76	0.37	0.024	0.031	0.024	0.0094	0.057	0.05	0.011	0.14
08/06/2015		0.27	0.82	0.55	0.022	0.026	0.044	0.01	0.13	0.053	0.01	0.15
09/06/2015		0.23	0.78	0.36	0.018	0.02	0.025	0.008	0.076	0.051	0.0083	0.16
10/06/2015		0.24	0.72	0.35	0.019	0.021	0.022	0.009	0.074	0.059	0.0083	0.15
11/06/2015		0.32	0.77	0.39	0.026	0.033	0.017	0.008	0.13	0.046	0.01	0.14
15/06/2015		0.28	0.78	0.43	0.012	0.017	0.024	0.008	0.077	0.05	0.003	0.15
17/06/2015		0.31	0.77	0.36	0.023	0.035	0.024	0.008	0.081	0.036	0.012	0.19
18/06/2015		0.28	0.78	0.43	0.022	0.039	0.016	0.008	0.096	0.046	0.01	0.18
19/06/2015		0.31	0.72	0.31	0.024	0.027	0.021	0.023	0.11	0.075	0.012	0.16
22/06/2015		0.3	0.72	0.31	0.021	0.029	0.005	0.032	0.1	0.082	0.01	0.14

											3	
23/06/2015		0.32	0.77	0.39	0.024	0.042	0.078	0.008	0.035	0.035	0.011	0.13
24/06/2015		0.25	0.69	0.34	0.025	0.036	0.0045	0.0085	0.062	0.068	0.073	0.15
25/06/2015		0.27	0.81	0.44	0.027	0.04	0.055	0.008	0.059	0.039	0.011	0.2
26/06/2015		0.24	0.82	0.48	0.02	0.028	0.057	0.012	0.064	0.047	0.0091	0.17
29/06/2015		0.25	0.75	0.4	0.025	0.03	0.02	0.008	0.056	0.05	0.05	0.14
05/07/2015		0.25	0.75	0.42	0.024	0.037	0.042	0.008	0.071	0.046	0.0096	0.15
06/07/2015		0.28	0.78	0.4	0.025	0.03	0.045	0.008	0.051	0.038	0.0083	0.15
07/07/2015		0.2	0.87	0.37	0.02	0.022	0.013	0.017	0.092	0.063	0.011	0.17
08/07/2015		0.22	0.78	0.35	0.021	0.026	0.03	0.03	0.084	0.08	0.011	0.0092
11/07/2015		0.26	0.73	0.34	0.027	0.027	0.014	0.0099	0.066	0.044	0.0098	0.15
12/07/2015		0.24	0.77	0.34	0.02	0.027	0.015	0.019	0.056	0.056	0.011	0.11
13/07/2015		0.21	0.77	0.36	0.018	0.02	0.036	0.011	0.06	0.043	0.0091	0.12
14/07/2015		0.21	0.87	0.48	0.018	0.021	0.0095	0.025	0.067	0.051	0.0094	0.14
15/07/2015		0.22	0.81	0.39	0.022	0.026	0.027	0.023	0.073	0.059	0.011	0.14
16/07/2015		0.24	0.81	0.42	0.022	0.021	0.014	0.008	0.082	0.066	0.0099	0.088
18/07/2015		0.29	1.7	0.58	0.028	0.035	0.015	0.011	0.3	0.032	0.011	0.34
19/07/2015		0.23	0.8	0.36	0.035	0.042	0.016	0.01	0.06	0.065	0.016	0.13
20/07/2015		0.16	0.8	0.38	0.027	0.031	0.012	0.008	0.034	0.042	0.01	0.14
16/08/2015		0.23	1.75	0.36	0.018	0	0.028	0.034	0.268	0.038	0.00	0.26

		8	1	3	6						4	2
17/08/2015		0.224	1.581	0.6	0.012	0	0.044	0.029	0.266	0.039	0	0.307
18/08/2015		0.242	1.542	0.446	0.018	0.021	0.021	0.036	0.3	0.039	0.004	0.263
21/08/2015		0.277	1.546	0.43	0.017	0.037	0.029	0.028	0.248	0.035	0.003	0.256
22/08/2015		0.221	0.798	0.314	0.017	0.048	0.033	0.046	0.071	0.052	0.004	0.212
23/08/2015		0.272	1.726	0.458	0.014	0.064	0.047	0.044	0.287	0.057	0.005	0.299
23/08/2015		0.262	1.46	0.427	0.017	0.033	0.027	0.091	0.26	0.054	0.004	0.233
25/08/2015		0.223	1.703	0.381	0.017	0.05	0.032	0.049	0.303	0.054	0.005	0.276
28/08/2015		0.297	1.592	0.401	0.02	0.046	0.032	0.051	0.269	0.06	0.005	0.275
02/09/2015		0.237	0.775	0.318	0.013	0.035	0.021	0.054	0.147	0.06	0.005	0.146
02/09/2015		0.28	1.498	0.498	0.018	0.053	0.034	0.061	0.262	0.07	0.006	0.32
05/09/2015		0.225	1.387	0.382	0.014	0.008	0.021	0.047	0.272	0.055	0.004	0.258
05/09/2015		0.228	1.28	0.363	0.012	0.014	0.032	0.055	0.272	0.065	0.004	0.26

12.8 Gauging after Dress after Weld

Table 12-12: Castings that gauge after Dress after Weld

Date	**Casting type**	**Total castings**	**Total Accepted**	**Do not Gauge**
01/07/2015	Brake shoes	72	72	0
02/07/2015	TCC	68	34	2
03/07/2015	Brake shoes	180	180	0
06/07/2015	Brake shoes	200	200	0

07/07/2015	TCC	13	7	0
08/07/2015	Brake shoes	99	99	0
09/07/2015	Brake shoes	228	228	0
10/07/2015	TCC	12	12	0
13/07/2015	Brake shoes	86	79	3
14/07/2015	Brake shoes	113	86	26
15/07/2015	Brake shoes	52	36	16
17/07/2015	Brake shoes	105	100	3
22/07/2015	Brake shoes	241	150	90
23/07/2015	Brake shoes	186	161	19
27/07/2015	Brake shoes	92	74	18
27/07/2015	TCC	8	8	0
28/07/2015	Brake shoes	74	31	25
03/08/2015	Brake shoes	74	31	25
04/08/2015	Brake shoes	75	68	6
05/08/2015	Brake shoes	93	0	0
06/08/2015	Brake shoes	199	199	0
07/08/2015	TCC	50	50	0
11/08/2015	Brake shoes	78	53	18
12/08/2015	Brake shoes	151	117	15
13/08/2015	TCC	24	24	0
14/08/2015	Brake shoes	138	123	6
17/08/2015	Brake shoes	204	189	3
19/08/2015	Brake shoes	440	440	0
20/08/2015	Brake shoes	467	414	49
24/08/2015	Brake shoes	173	140	0
26/08/2015	Brake shoes	196	159	28
01/09/2015	Brake shoes	352	108	62
02/09/2015	Brake shoes	254	232	22
03/09/2015	Brake shoes	438	166	272
03/09/2015	TCC	20	20	0
08/09/2015	Brake shoes	410	354	51
09/09/2015	Brake shoes	161	131	25
10/09/2015	Brake shoes	320	220	94
11/09/2015	TCC	9	9	0

15/09/2015	Brake shoes	566	434	117
16/09/2015	Brake shoes	101	77	21
17/09/2015	Brake shoes	171	111	55
18/09/2015	Brake shoes	146	137	8
18/09/2015	TCC	15	15	0
21/09/2015	Brake shoes	499	494	17
23/09/2015	TCC	17	17	0

12.9 Heat treatment curve

Table 12-13: Heat treatment data

Spec						
Date	**Ramp up duration(h)**	**Ramp up temperature**	**Soaking duration (h)**	**Soaking temperature (Degrees)**	**Cooling duration (h)**	**Cooling temperature (degrees)**
11/06/2015	2	629.9	3.5	629.9	6	153.5
10/06/2015	Reheat					
12/06/2015	1.5	545	2	545	4	36.1
14/06/2015	2	813	2	813	3.5	0
16/06/2015	2.5	865	2	865	3.5	67.9
22/06/2015	1.5	838	3.5	838	4	0
29/06/2015	2	829	3.5	829	6	235
30/06/2015	2	776	2.5	776	4	0
01/07/2015	Reheat					
06/07/2015	2	900	3	900	7	415
12/07/2015	1.5	800	2	800	2.5	123
13/07/2015	2	820	3	820	7	99
15/07/2015	1	900	2	900	3.5	329
16/07/2015	Reheat					
22/07/2015	2.5	810	3.5	810	6	223
28/07/2015	Reheat					
04/08/2015	Reheat					
07/08/2015	2	828	2	828	3.5	323

08/07/2015	Reheat					
09/07/2015	2	900	3	900	7	472.4
11/08/2015	2	960	2	960	4	221
13/08/2015	2	940	2	940	5	150
16/08/2015	Reheat					
17/08/2015	Reheat					
19/08/2015	3.5	880	3	880	4	41.7
18/08/2015	1	720	2.5	720	3	349
09/09/2015	Reheat					
11/09/2015	1.5	900	2	900	5	305
14/09/2015	1.5	731	3.5	731	9	131
15/09/2015	2	688	3	688	8	91
16/09/2015	2	862	3	862	7	262
17/09/2015	2	643	3	643	7	173
22/09/2015	2.5	796	2.5	796	8	196
23/09/2015	Reheat					

12.10 Cost to manufacture top centre castings

It is imperative that the manufacturing cost for the top centre casting is understood so as to establish the cost quality relative to it. Calculation for the cost of manufacturing top centre casting from first principles has been outlined below. For the manufacture of top centre castings chemically bonded sand is used and resin and catalyst are added accordingly.

Sand (Top centre casting)

Sand used = 457Kg

Resin (1.6% of sand used) = 7.31Kg

Mould = 464 Kg

Catalyst (21% of Resin) = 1.54Kg

Cost of Resin = 7.31Kg x R13.75/Kg = R100.54

Cost of Catalyst = 1.54Kg x R25.70/Kg = R39.58

Cost of Sand = 448Kg x R0.44/Kg = R197.19

Sleeves = 8 X R30.15 each = R241.20

Total cost for sand + additives = R 578.51

Melt

When scrap is melted in the induction furnace, additives such as manganese, silicon and other metals are added. For the top centre castings, Table 12-14 shows the amounts of each of the metals that are added.

Table 12-14: Melt additives

Additives			
Material	**Quantity used (Kg)**	**Cost per Kg**	**Cost for amount used**
MC Fe Mn	55	R21.55	R1 185.25
Fe Silicon	78	R17.60	R1 372.80
Al Deox 94%	6	R22.40	R134.40
Flucast	2.8	R7.14	R19.99
Calsif 2-7mm	2.8	R29.32	R82.10
Zincoment L7-20	2.8	R62	R173.60
Mo	16	R236	R3 776.00
Ni	6	R146	R876.00
Bearings	99	R0.26	R25.44
Total (Kg)	**268.4**		
Total for additives	**R7 645.59**		

Scrap

The scrap metal that is used to charge the induction furnace should be 9000kg in mass and the different additions that are supposed to be added can be seen in Table 12-15. In the furnace melting sheet 38 top centre castings were casted on the day the observation was made.

Cost of scrap per kg = R3.85

Table 12-15: Scrap metal additions

Material	Mass(Kg)		Cost
Additives	268.4	9000	R7 645.59
Scrap	8731.6		R33 616.66
Slag	1000		R4 584.69
Bogies (38)	8000		R36 677.56

Cost of melting for one Bogie = R36 677.56/38
= R965.19

The cost of melting one top centre casting has been calculated to be R965.19.

Electricity

The induction furnace consumes a lot of electricity when the scrap is being melted and prepared to become molten metal. Table 12-16 shows the breakdown of how the molten metal is used and how much of molten metal becomes slag.

Furnace electricity cost

Electricity cost per hour = R681.58

Time to prepare a melt= 6.5 hours

Total cost for melting 9000kg = R4 432.03

Furnace electricity cost for one bogie= R103.67

Table 12-16: Cost of melting a bogie

Cost of melting per component				
Product	**Mass(kg)**	**Cost**	**Units made**	**Cost per component**
Bogie/48	8000	R3 939.58	38	R103.67
Slag	1000	R 492.45		
Total	**9000**	**R4 432.03**		

Heat treatment

Heat treatment is a process that also consumes electricity. Heat treatment is done to ensure that castings are normalised and they are stronger. Top centre castings are bigger castings in size and they are normalised for 12 hours. Table 12-17 shows the different tariffs that are incurred by the Foundry when heat treatment is done either in winter or in summer for the 12 hour cycle.

Table 12-17 : Heat treatment cycles

12 Hour Cycle		Season	
Power (kW)	Shift	Winter	Summer
600	Day	R9 753.00	R3 979.00
600	Night	R3 074.00	R2 479.00

Total heat treatment per component

- Winter = R3 074/38 = **R80.89**
- Summer = R2 479.00/38 = **R65.24**

The total heat treatment cost per top centre in winter is R80.89 and in summer it is R65.24.

Labour cost per department

Labour costs should be calculated in the manufacturing cost of the castings as value is added at each and every stage in the process. The labour costs per process can be seen in Table 12-18.

Table 12-18: Labour cost per process

Labour Cost				
Process	**Fixed number of Operators**	**Cost of operator/h**	**Time spent at Station (hours)**	**Total**
Moulding and core making	6	R 57.09	1.21	R 414.49/38=R10.91
Melting	10	R 57.09	6.0	R3425.40/38 = R90.14
Casting	7	R 57.09	0.5	R 485.27/38= R 12.77

Shot blasting	6	R 57.09	1.48	R 506.96/38= R13.34
Heat treatment	2	R 57.09	12	R 1370.16/38= R36.06
Cutting	1	R 57.09	0.5	R 28.55
Dress to gauge	1	R 57.09	0.5	R 28.55
Dress after weld	1	R 57.09	0.16	R 9.13
Total cost per Bogie	**R229.45**			

The total cost for labour for the value added to the top centre casting is calculated to be R229.45 for one casting.

Fettling

Dress to gauge is one of the fettling processes that has been outsourced. Dress after weld is the only process that has been left in-house. Castings are sent out to the supplier for cutting and dress to gauge and they only come back for dress to weld. Table 12-18 shows the cost of doing dress after weld in-house. To grind top centre castings a cup stone is used and I disk can grind 12 top centre castings. The cost of grinding one top centre casting was therefore calculated and it can be seen in Table 12-19.

Table 12-19: Dress after weld costing

Fettling Consumable materials			
Material	**Quantity Used**	**Cost per Item**	**Cost of used quantities**
Cup Stone(DAW) (I disk = 12 Bogies)	0.083	R187.58	R15.57
Total cost			**15.57**

From Table 12-19 the cost of doing dress after weld on the top centre casting has been calculated to be R15.57.

The total manufacturing cost for the top centre casting can be summarised as follows: Raw materials (Sand + additives) = R578.51

+ Fettling raw materials = R15.57
+ Melting (Scrap + Additives = Charge) = R965.19
+ Electricity (Melting + Heat treatment cost) = R184.56
+ Labour cost = R229.45
=R1 973.28

The study also involved brake shoe holders and they were studied to understand the cost of manufacturing from first principles. Brake shoes holders are manufactured from green sand and additives such as bentonite and starch are added.

Cost to manufacture brake shoe holders

Sand

The sand that is used to create moulds for brake shoe holders contains new and reclaims sand. Tests are done in the sand laboratory to ensure that the permeability, compactability and moisture among other things comply with specification.

Sand = 308.95Kg (Reclaim & New sand)

Bentonite (5% of sand) = 16.7 Kg

Starch (2.5% of sand) = 8.35 Kg

Total Weight of Mould = 334 Kg

Cost of Bentonite = R2.50/Kg x 16.7Kg = R41.75

Cost of Starch = R35/Kg x 8.35Kg = R292.25

Cost of new sand (5%) = 16.7Kg x R0.438/Kg = R 7.31

Cost of reclaim sand (95%) = 317.3Kg x 0 = R0

Sleeves = 1 x R40.00 = R40.00

Cores (/17) = 1xR22.45 + 1x25.70 = R48.15

Total cost for sand + additives = R429.46

Total cost for sand + additives (4) = R429.46. One mould contains four brake shoe holders and therefore the cost for one brake shoe holder would be R429.46/4 and it becomes R107.7.

Metal Additives

Preparing molten metal for brake shoe holders requires that metals such as manganese, flucast and silicon be added to the scrap that is being melted to ensure that the chemical composition complies with specification. Table 12-20 shows composition of the quantities that are added to the molten metal for making brake shoe holders.

Table 12-20: Melt Additives for brake shoe holders

Additives			
Material	**Quantity used (Kg)**	**Cost per Kg**	**Cost for amount used**
MC Fe Mn	45	R21.55	R538.75
Fe Silicon	53	R17.60	R668.80
Flucast	3.4	R7.14	R24.28
Calsif (2-7mm)	3.4	R29.32	R99.69
Al Deox 94%	5.5	R22.40	R123.20
Zircoment L7-20	34	R62.00	R2 108.00
Bearings	300.7	R0.26	R78.18
Total (Kg)	**445**		
Total (Rands) for additives	**R 3 640.90**		

Scrap

To make brake shoe holders scrap metal which is 7000kg is charged onto the induction furnace to form molten metal. Of the 7000kg scrap metal that is charged, 1000kg of that becomes slag and 6000kg becomes useful molten metal. When the observations were made 152 brake shoe holders were made. Table 12-21 shoes the cost of preparing molten metal. The cost of scrap per kilogram is R3.85.

Table 12-21: Scrap metal added to the induction furnace

Material	**Mass (Kg)**		**Cost(R)**
Additives	445	7000	R3640.90
Scrap	6555		R26 950.00
Slag	1000		R5098.48
Brake shoes(152)	6000		R26 220.77

Cost of melting for one Brake shoes =R 26 220.77/152

= R172.51

The calculated cost to prepare molten metal for one brake shoe holder was calculated to be R172.51.

Electricity cost: Melting furnace

It is important to calculate cost of electricity consumed when melting scrap. The cost of electricity that is consumed per hour in the induction furnace is R681.58 per hour. Table 12-22 shows the cost breakdown for electricity for melting scrap.

Furnace electricity cost

Electricity cost per hour = R681.58

Time to prepare a melt = 6.5 hours

Total cost for melting 7000kg = R 4 430.27

Furnace electricity cost for one Brake shoes = R 24.98

The cost that was calculated for electricity for one brake shoe was found to be R24.98.

Table 12-22: Cost of melting per component

Cost of melting per component				
Product	**Mass(kg)**	**Cost**	**Units made**	**Cost per component**
Brake shoes (152)	6000	R3 797.37	152	R24.98
Slag	1000	R632.90		

Heat treatment cost

Castings require to be normalised to ensure that carbides are removed and the casting is strengthened. Heat treatment for brake shoe holders for a 12 hour cycle in summer and in winter can be seen in Table 12-23.

Table 12-23: Heat treatment cost for brake shoe holders

12 Hour Cycle	Season

Power (kW)	Shift	Winter	Summer
600	Day	R9 753.00	R3 979.00
600	Night	R3 074.00	R2 479.00

Total heat treatment per component

- Winter = R3 074/152 = R 20.22
- Summer = R2 479.00/152 = R 16.30

The total cost for heat treatment in winter for a brake shoe holder was calculated to be R20.22 in summer it was calculated to R16.30.

Labour cost

Labour costs were calculated to ensure value that is added to the castings at different stages is taken into account. Table 12-24 shows the labour cost for different processes.

Table 12-24: Labour costs for manufacturing brake shoe holders

Labour Cost				
Process	**Fixed number Operators**	**Cost of operator/h**	**Time spent at Station (hours)**	**Total**
Moulding and core making	6	R 57.09	1.21	R 414.49/152=R2.73
Melting	10	R 57.09	6.0	R3425.40/152 = R22.53
Casting	7	R 57.09	0.5	R 485.27/152= R 3.19
Shot blasting	6	R 57.09	1.48	R 506.96/152= R3.34
Heat treatment	2	R 57.09	12	R 1370.16/152= R9.01
Cutting	1	R 57.09	0.	R 28.55
Dress to gauge	1	R 57.09	2.0	R 114.18
Dress after weld	1	R 57.09	0.16	R 9.13
Total cost per Brake shoes	R192.66			

From Table 12-24 it was established that the cost of labour to for brake shoes was calculated to be R192.66.

Fettling raw materials

Fettling has been outsourced at Foundry mainly cutting, shot blasting and dress to gauge and only dress after weld is still done in house. Table 12-25 shows the fettling cost for dress after weld.

Table 12-25: Fettling cost for brake shoe holders

Fettling Consumable materials			
Material	**Quantity Used**	**Cost per Item**	**Cost of used quantities**
Grinding disks (DAW) 1 disk=8 brake shoes	3	R9.63	R28.89
Total cost	**R28.89**		

The total cost that was calculated for doing dress after weld was calculated to be R28.89.

The total manufacturing cost of brake shoes = Raw materials (Sand + additives) = R107.37 + Fettling raw materials = R28.89

+ Melting (Scrap + Additives = Charge) = R 172.51

+ Electricity (Melting + Heat treatment cost) = R45.20

+ Labour cost = R192.66

= R546.63

12.11 Cost of quality

For any foundry system it is imperative to design a quality system that includes the concerns of the customer and this can be done by utilising the existing quality standards to calibrate the process performance and product quality. Rejection diagnosis sheet can be drawn to quantify non-conformance costs related internal quality standards.

A summary table has been drawn up to illustrate the instances when in the casting process there were deviations to the prescribed specification. This is shown in Table 12-26.

Table 12-26: Process out of specification

Section in the plant	**Process**	**Property**	**Out of specification%**

Green sand	Return Green sand	Fines	36%
	Return Green sand	AFS	75%
	New sand	Fines	44%
	New sand	AFS	84%
Resin Bonded sand	Mould making-Chemically bonded sand		66%
Moulding	Mould making-Chemically bonded sand		1.56%
Furnace	Melting		11%
Fettling	Dress after weld (Do not gauge)		15%
Fettling	Dress after weld (Rework)		6%
Heat Treatment	Heat treatment		29%

Components of cost of quality

Prevention costs- These are costs incurred by an organisation when they try to investigate prevent or reduce the risk of non-conformity. These costs are planned and are associated with the design, implementation and maintenance of a total quality management system (Zimwara, Mugwagwa, Maringa, Mnkandla, Mugwagwa, & Ngwarati, 2013).

The foundry in the financial years 2013/2014, 2014/2015, 2015/2016 sent their employees to TUV Rheinland for the ISO 9001 Internal Auditor course. Table 12-27 shows the table of the attendees who have attended the internal audit course and some people who are still to attend the course.

Table 12-27: Audit training course at TUV Rheinland

Financial year	Number of attendees	Cost	Total costs
2013/2014	3	R 4 000.00	R 12 000.00
2014/2015	4	R 4 530.00	R 18 120.00
2015/ 2016	5	R 5 392.20	R 26 961.00

In 2013/2014 the Foundry sent 3 people and in 2014/2015 they sent 4 people and in 2015/2016 the business is planning to send 5 people for training. Figure 12-27 shows the prevention costs which the foundry has taken to ensure that defects are minimised from occurring. By 2016 the Foundry business would have spent R57 081.00 towards prevention costs.

12.12 Sand AFS and Fines

Table 12-28: AFS and Fines data

Sample	AFS 5	AFS 10	AFS 25	Fines 5	Fines 10	Fines 25
1	44.68	45.89	46.49	1.37	2.11	0.7
2	43.9	44.02	43.86	1.03	0.6	0.91
3	45.42	44.45	40.81	0.88	1.14	0.55
4	44.27	41.31	44.54	1.39	0.67	0.47
5	43.01	42.1	40.08	0.97	0.4	0.27
6	46.15	39.73	46.42	1.07	0.43	1.28
7	40.69	42.05	47.01	0.24	1.04	4.13
8	40.03	44.51	46.86	0.4	4.72	0.29
9	41	41.3	40.8	2.3	0.93	1.41
10	37.55	35.36	41.01	1.19	1.53	0.81
11	43.7	35.73	44.54	0.62	1.01	1.34
12	44.07	42.41	42.34	1.38	3.35	0.27
13	44.31	33	41.79	0.53	0.14	0.65
14	41.28	40.09	46.38	1.18	1.08	1.58
15	44.19	41.95	45.21	1.35	1.08	2.8
16	42.26	42.47	46.04	0.47	1.57	4.07
17	41	42.1	44.04	0.93	0.87	1.44
18	40.9	47.18	40.85	0.81	2.11	0.98
19	41.78	40.77	41.72	0.58	0.67	0.3
20	39.6	45.2	45.44	0.36	7.38	0.92
21	42.6	47.72	42.09	0.38	2.97	0.56
22	40.26	48.22	44.24	1.08	3.12	3.8
23	43.7	37.77	39.81	1.44	0.18	1.02
24	40.7	47.43	40.05	0.96	6.15	0.99
25	45.1	53.64	40.86	1.48	9.51	0.83
26	38.35	49.96	39.78	0.11	6.76	0.6
27	39.76	57.94	42.99	0.68	12.57	1.8

28	46.29	67.2	34.36	1.96	17.85	0.22
29	40.96	60.77	40.57	0.29	10.37	0.8
30	39.67	54.44	41.69	0.34	12.53	1.37
31	41.9	56.56	39.1	2.45	11.13	1.1
32	38.88	56.56	42.09	0.47	12.08	0.65
33	39.9	42.07	40.17	0.5	1.29	1.08
34	38.23	34.48	42	0.25	1.72	1.41
35	40.74	38.11	45.87	1.44	3.12	1.11
36	43.87	51.4	41.43	3.46	6.23	1.96
37	42.47	40.16	39.75	0.45	2.95	0.68
38	38.86	58.89	48.61	0.16	13.12	5.2
39	41.29	48.85	39.45	0.56	7.17	0.51
40	41.99	52.49	43.99	1.04	8.6	0.86
41	43	48.53	43.58	1.62	6.52	2.3
42	40.7	43.4	44.9	1.08	6.2	2.61
43	39.46	55.08	48.69	0.65	10.83	6.28
44	44.89	48.82	49.13	3.42	4.39	3.57
45	38.02	46.26	54.35	0.34	9.27	5.57
46	41.24	52.87	52.82	2.7	10.71	6.55
47	41.66	36.78	33.73	1.19	0.58	0.17
48	40.52	71.05	45.62	0.9	15.6	4.9
49	45.5	43.96	52.57	4.19	5.67	3.73
50	38.74	63.75	49.26	1.59	11.87	5.97
51	39.43	42.78	45.88	1.17	4.74	2.38
	41.73470588	46.85411765	43.640392	1.1254902	5.267254902	1.87745098

12-13 10 Ton Machine Observations

Table 12-29: AFS for 5 ton Machine

Date	Shift	AFS	AFS Spec (45-60)	Fines	Fines - Spec (3-5 sieves)
12/01/2015	Day	44.68	FALSE	1.37	FALSE
13/01/2015	Day	43.9	FALSE	1.03	FALSE

15/01/2015	Day	45.42	FALSE	0.88	FALSE
16/01/2015	Day	44.27	FALSE	1.39	FALSE
19/01/2015	Night	43.01	FALSE	0.97	FALSE
20/01/2015	Night	46.15	TRUE	1.07	FALSE
21/01/2015	Night	40.69	FALSE	0.24	FALSE
22/01/2015	Night	40.03	FALSE	0.4	FALSE
24/01/2015	Day	41	FALSE	2.3	FALSE
25/01/2015	Day	37.55	FALSE	1.19	FALSE
26/01/2015	Night	43.7	FALSE	0.62	FALSE
28/01/2015	Day	44.07	FALSE	1.38	FALSE
28/01/2015	Night	44.31	FALSE	0.53	FALSE
29/01/2015	Day	41.28	FALSE	1.18	FALSE
29/01/2015	Night	44.19	FALSE	1.35	FALSE
30/01/2015	Night	42.26	FALSE	0.47	FALSE
02/02/2015	Day	41	FALSE	0.93	FALSE
03/02/2015	Day	40.9	FALSE	0.81	FALSE
03/02/2015	Day	41.78	FALSE	0.58	FALSE
04/02/2015	Night	39.6	FALSE	0.36	FALSE
05/02/2015	Night	42.6	FALSE	0.38	FALSE
09/02/2015	Day	40.26	FALSE	1.08	FALSE
09/02/2015	Night	43.7	FALSE	1.44	FALSE
10/02/2015	Day	40.7	FALSE	0.96	FALSE
11/02/2015	Night	45.1	TRUE	1.48	FALSE
13/02/2015	Day	38.35	FALSE	0.11	FALSE
23/02/2015	Night	39.76	FALSE	0.68	FALSE
23/02/2015	Day	46.29	TRUE	1.96	FALSE
25/02/2015	Day	40.96	FALSE	0.29	FALSE
02/03/2015	Night	39.67	FALSE	0.34	FALSE
03/03/2015	Night	41.9	FALSE	2.45	FALSE
04/03/2015	Night	38.88	FALSE	0.47	FALSE
04/03/2015	Day	39.9	FALSE	0.5	FALSE
06/03/2015	Night	38.23	FALSE	0.25	FALSE
07/03/2015	Day	40.74	FALSE	1.44	FALSE
10/03/2015	Day	43.87	FALSE	3.46	TRUE

10/03/2015	Night	42.47	FALSE	0.45	FALSE
11/03/2015	Day	38.86	FALSE	0.16	FALSE
11/03/2015	Night	41.29	FALSE	0.56	FALSE
12/03/2015	Day	41.99	FALSE	1.04	FALSE
13/03/2015	Day	43	FALSE	1.62	FALSE
31/03/2015	Day	40.7	FALSE	1.08	FALSE
01/04/2015	Day	39.46	FALSE	0.65	FALSE
07/04/2015	Day	44.89	FALSE	3.42	TRUE
08/04/2015	Day	38.02	FALSE	0.34	FALSE
09/04/2015	Day	41.24	FALSE	2.7	FALSE
13/04/2015	Day	41.66	FALSE	1.19	FALSE
14/04/2015	Day	40.52	FALSE	0.9	FALSE
15/04/2015	Day	45.5	TRUE	4.19	TRUE
16/04/2015	Day	38.74	FALSE	1.59	FALSE
20/04/2015	Day	39.43	FALSE	1.17	FALSE
		41.74	0	1.469194	0
		41.74			

AFS 5 Ton		
TRUE	5	8.06%
FALSE	57	91.94%
Observations	62	

12.14 Mould Hardness

Table 12-30: Green sand mould hardness

Specification (80-100)	
Observation	Average Sample Hardness
1	88.50
2	88.17
3	88.33

4	87.67
5	88.50
6	89.00
7	87.83
8	87.83
9	88.00
10	88.83
11	88.83
12	88.50
13	88.33
14	88.50
15	88.67
16	88.50
17	88.33
18	88.17
19	88.67
20	88.50
21	88.33
22	88.33
23	88.33
24	88.00
25	88.67
26	87.83
27	88.17
28	88.00
29	87.83
30	88.50
31	88.83
32	88.83
33	88.83
34	88.83
35	88.33
36	87.83
37	87.83
38	88.00

39	88.17
40	88.33
41	88.33
42	88.50
43	88.17
44	88.67
45	88.17
46	88.33
47	88.83
48	89.33