ALUMINOTHERMIC WELDING MANAGEMENT USING LEAN SIX SIGMA METHODOLOGY ON THE SOUTH AFRICAN COAL EXPORT LINE

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SUMMARY

This paper is a report on the methodology and results obtained through an application of the Lean Six Sigma Methodology in the rail welding process for the South African Coal Export Line. An in-depth root cause analysis and the implementation of change management interventions provided possibilities for improvement. Control frameworks, the streamlining of processes, waste reduction as well as short and long term solutions, were implemented to ensure continuous improvements are obtained with the welding performance and the occurrence of rail breaks and defects are limited.

1. INTRODUCTION

The South African Coal Export line is a heavy haul line of 26 ton axle loading from the Mpumalanga coal fields to the Richards Bay Coal Terminal which also accommodates GFB traffic. The 580 km long double line carried 70.8 MT of export coal in 2013\(^1\) on UIC 60 kg/m continuously welded rails. The rails are welded using single-use crucibles for aluminothermic (thermite) welding.

Rail welding is done during rail replacement or repair, set or component replacement and for the removal of rail defects, either Ultrasonic measuring car (UMC) detected or welding defects. All these maintenance activities are primarily due to fatigue wear, with the exception of welding defects that are man-made defects in the thermite weld. This paper focuses on welding defects and their occurrence\(^2\).

2. NOTATION

<table>
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<tr>
<th>Symbol/abbreviation</th>
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<td>GFB</td>
<td>General Freight Business</td>
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<td>H1, H2, H3</td>
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Table 1

3. BACKGROUND

Rail breaks are serious incidents that can lead to derailments. In the first and second quarter of the 2013/2014 financial year, the coal line across the 3 maintenance depots experienced 32 rail breaks\(^3\). Rail breaks are a sudden and unplanned discontinuity in a continuously welded rail. These lead to derailments wagon wheels, full bogie or entire wagon(s), causing great disruptions to the railway network for the safe passage of trains. This is demonstrated by the 18 train slot cancellations and 6520 minute delays of export coal and GFB trains in these two quarters\(^4\). 52% of the rail breaks that
occurred in the first and second quarter took place on or adjacent to thermite welds as shown in figure 2°.

Welds of low integrity experience fatigue damage or fracture and the uneven surface of the rail crown induces dynamic impact loads. The mechanism of rail breaks as a result of welding defects is crack propagation as a result of impact loads and high stresses. Considering the yield strength of the UIC 60 kg/m rails used on the coal line, the rail will break when the stress level of the load bearing area exceeds the value of 141 Mpa. With the conventional rail designed to carry tension, compression and bending forces, it is important to have a rail with a uniform internal structure. Internal welding defects act as stress raisers within the rail and thus making them prone to breaking under normal working loads5,6.

Aluminothermic welding defects are caused by a variety of factors ranging from following incorrect rail welding procedure, rail temperature variations and incorrect preparation work beforehand. Often the type of defect that arises is an indication of a certain part of the thermite welding process having gone wrong. Thermite welding defects exist beneath the surface, decreasing the defect’s visibility and thus leading to sudden failures (rail breaks) without warning2,4.

X-ray testing and joggle fish plates are used as the first line of defence against defective thermite welds and as a safety precaution while waiting for X-ray testing and results or for the removal of known defects. The X-ray results inform maintenance departments on the whether the weld is safe, or to be removed from the line under planned or emergency conditons2. This intervention is reactive in nature as it detects defective thermite welds after they have occurred.

A more proactive intervention has been the region-wide implementation of the single-use crucible13. The single-use crucible has significantly reduced the risk of certain types of defects from occurring, namely, inclusions12.

This intervention has managed to decrease the cut out rate significantly. However, its benefits remained disproportional throughout the Coal Line with Depots not recording the same changes since its inception due to poor data recording. The root cause of the high defect rates still remained unknown9,10,11,12.

4. METHODOLOGY

The methodology used to achieve the objective is the Lean Six Sigma methodology. This methodology requires project leaders to objectively assess a problem without any previous bias.

A webpage explaining the brief history of lean, highlights that the Lean methodology based on the thought processes developed as the Toyota Production System (that addressed the problems Henry Ford experienced in the production of the Model T Ford) and thoroughly described in the book, *The Machine That Changed the World* by Womack, Roos and Jones. It is now used worldwide as a part of RCA, with its application having experienced changes, but its principles remaining the same and applicable to most sectors, including maintenance.7

The DMAIC (Define, Measure, Analyse, Improve, and Control) concept was utilised as a guide to:

1. Correctly define the problem, its impact to the business and the scope of the project
2. Accurately measure relevant data
3. Analyse data and extract the correct conclusions
4. Implement recommendations to improve the situation
5. Set up control measures to ensure that objectives are being met in order to make necessary adjustments if necessary8

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5. ANALYSIS

As often is the case with large projects, incorrectly defined parameters can be the difference between a successfully implemented project that meets its objectives and a successfully implemented project that does not do what it was initially intended to do. It is important for a project leader to always have the vision of the end state in mind when carrying out improvement/turnaround projects as there will be instances where the focus may shift due many factors that can arise during a project.

Using the Lean Six Sigma Methodology, what is critical to the customer becomes the main influence to the objective. In this project, the persons who have a vested interest in welding performance are the depot Engineer, Perway Maintenance Manager and Production Manager. What was found to be critical to the customer was the timely removal of defects, their high occurrence and their severity. For these reasons, the primary metric for the project was selected as a welding cut out rate of 5% or less.

As per the measuring phase, data was collected from the incidents recorded in figure 1 to determine the impact of these welding defects on the business. Focusing on the root causes and frequency of these welding related incidents, showed that reducing the cut out rate would save costs in terms of repairs, overtime hours, rails, materials and reduce the income losses due to a loss of traffic. The second source of data information was found from the X-ray evaluation results obtained from a laboratory. This indicated the highest occurrence in defects as wormholes and inclusions.

However, a statistical desktop analysis demonstrated to be very high level and highly unreliable. The reasons for these formed part of the investigation. This phase is not only about the gathering of quantitative data, as the root cause of the problem may be a combination of factors. The measuring phase also includes engaging with the relevant stakeholders and team members involved in every step in the process that leads to and follows after the welding activity.

![Types of rail breaks](image)

(Figure 1)

In order to ensure a systemic approach to the problem, this process was mapped as shown in figure 2. Mapping it as it currently is with all its inputs and outputs, the waste (non-value adding activities) were eliminated and a new process with minimum waste was identified as shown in figure 3. The waste identified included:

1. The waiting for x-ray results and for defects to be removed (cut out),
2. Over-production as a result of stock materials expiring,
3. The re-work involved in re-casting welds as a result of removing defective ones and
4. Over-processing of X-ray results when too many persons are required to verify the results.
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(Figure 2)

(Figure 3)

Upon elimination of the identified waste, the process would be a streamlined, efficient process as shown on this page.
Brainstorming sessions were held with welders, trainee welders and managers separately. This was followed with welding forums with welders, trainees, material suppliers and the welding technical office in Transnet. This was done in order to find the root cause of the defined problem. The issues identified were categorised as per the fishbone diagram method, which is used to diagrammatically organise root causes into the categories of environmental, machine, staff, tools, process, measurements and materials. These were conducted separately for each depot and the results of the root causes for the welding cut out rate are shown in figure 4.

The information gathered in the measure phase feeds into the problem identification mechanisms embedded within the Lean Six Sigma Methodology. In this project fishbone diagrams were used to categorise and display identified challenges under the relevant classification. The XY-matrix, which ranks the root causes using severity and probability factors, facilitated the identification, as per the Pareto Principle, of 20% of challenges that caused 80% of the defects (figure 5). This allowed for solutions that targeted the challenges that contributed the most to the problem in order to optimise the allocation of resources.
6. RESULTS

The results of the Define, Measure and Analyse phases of Lean Six Sigma showed that the root causes with the highest severity and probability, provide the greatest risk to an increase in welding cut out rates on the coal line. An action plan was devised with a responsibility matrix and a control plan then implemented to ensure that the actions are implemented and the depots can continue striving for continuous improvement. The forums were conducted tri-monthly to ensure accountability, performance management and stakeholder engagement. Furthermore, the platform was used to continue identifying other technical root causes to defects and propose solutions. The results of the project are shown in figure 6.
7. RECOMMENDATIONS

In the improve and control phases of the Lean Six Sigma Methodology, an action was devised for each critical root cause identified in the 20% bracket through the application of the Pareto Principle. Some of the recommendations that were made to improve the rail welding process and reduce the welding cut out rates on Heavy Haul lines are highlighted in this section.

The root cause with the greatest influence was found to be employer-employee relationship and other staff related problems. Recommendations include introducing quality assurance processes on site through supervisions and documentation. Ideally, this would include the appointment of supervisors that have welding expertise, such as Welding Technical Superintendents or creating a peer mentoring environment amongst the top performing and poorly performing welders, trainees and the more experienced welders.

Creating targets for welders to work towards will incentivize the work and highlight the importance of welding. In line with training and supervision, creating a pool of expertise and qualified individuals is required to will provide welders with a platform to grow in their career.

Welding forums to address the storage and transportation of materials and welders who were high performers were commended at depot events and bad performers had their tools, machines and welding procedures audited for faults. Lastly, the accountability for welding performance has now been shared amongst other Perway employees as welder identification codes are now a requirement on every new weld and include a code for both the welder who cast the weld and the track master who prepared the rails for welding.

Minimising waste in the process was critical to the continuous improvement of the project and the Technical officer for welding was made the process owner. Problems with the turnaround times for welding and the lack of control at
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9. REFERENCES


8. Price Waterhouse and Coopers. Introduction to Lean Six Sigma
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Figure 7 Manual for track maintenance