Microstructural analysis of rail tracks defects: case study

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Abstract. This case study reports on the microstructural analysis performed on the railway with defect. The idea behind was to quantify the origin of these defects that are regular in Western Cape railway network. The chemical composition of the defect revealed the reduction in carbon and manganese content on the surface of the defect. The specimens extracted from the beginning and the end of the defect had higher hardness values compared to those extracted in the middle of the defect. This trend is in correlation with the chemical composition variations. The optical microscopy revealed the decarburization layer at the surface of the defect. This kind of the layer results from the surface being exposed to a constant high temperature. It was then concluded that the South African environmental conditions do not form part on the formation of this failure.

1. Introduction
Transportation is one of the key component that connect or brings humankind together. There are different modes of transports which serve different purposes. The diversity of transportation involves air-transport, road transport, rail transport, water transport, etc. There are constant improvements that are in progress in each and every mode of transportation. These improvements are stemming from unique challenges faced by each mode of transport. In most cases, the environmental conditions use to contribute towards each challenge faced by different mode of transportation. The rail transport is also one of the mode of transportation which historically has been facing failure problems due to harsh environmental conditions. However, these environmental conditions get access to this infrastructure due to either poor maintenance or poor installation of the railways. The poor installation of railway lines involves the joining technique (or welding technique) of the railways. In some cases, the failure is caused by the overloading of the vehicles that uses the railways [1].

There has been a strong upward trend in derailments over the last few years [2]. The analysis of derailments indicates that the most significant single contributor to derailments are rail breaks. The derailments originate from the cracks that are caused by different factors [3]. There has been a lot of work that has been performed in trying to mitigate and quantify the derailments. This includes the improvement and the optimization of the design prior to the installation of the rail network. The designs factor in the environmental conditions which impacts on the performance of the rails. In as much as the development is being made towards the design side, the derailments are still occurring in different parts of the world. However, these derailments differ country to country. This difference is caused by numerous factors. Those factors include the safety regulations and operations, the style and the type of rail users, the grade of the material used in constructing the railway network, etc. [4-6].
Typical example of the country based derailment is the type that occurs in Netherland called squat. This type of failure is common between conventional rails and high speed rails. They also occur on both rails with wooden and concrete sleepers. There are number of factors which contribute towards the initiation of the squats. This involves the vertical irregularities on the top of the rail which are resulting from the wheel burn and the indentations. The recognition of the squats resulted to intense research conducted with the purpose of eliminating them. The intensity of research resulted to the split approach towards their study. The splits involved metallurgical approach, squat initiation, detection and prevention approach and lastly squats growth approach [7]. It was discovered that the squats could be categorized into two main categories i.e. passive and active type. The active type of the squat is the type that is arising from the spontaneous differential wear and differential deformation which is encouraged by the material inhomogeneity which results from poor construction of tracks. On the other hand, the passive type of squat is the type that normally emerges from defects that are caused by external factors like indentations which are as a result of rail burn which is caused by the wheel slip. The surfacing of the squats has motivated the development of numerical studies which were aiming at studying the cracks of the squats at different environmental conditions. The growth and the development of numerical analysis were such that they could even predict the impact of the trapped liquid on the squat cracks [8].

There is also a lot of work that looks at the different factors that affect the life of the rails in different countries. These developments are incorporated to the standards and designs used to install the railway lines. These developments are mostly based on the field work or experiments that mimic the real situations. These developments were further complemented by the development of numerical analysis. Those numerical developments were used in estimating the life span and various factors impacting on the railways [9-13]. The majority of the developed numerical methods use the rolling contact fatigue (RCF) approach in predicting the life span of railways [14].

This paper is looking at analysing the defect that are occurring on the railway network in the Western Cape in South Africa. The origin of these railway defects are not known yet hence the initiation of this study. The maintenance of these defects involve taking off the affected area through the use of hand grinders. This method might have a negative impact towards the microstructure of the railway. However, this is not part of the analysis in this paper.

2. Methodology
The railway piece with defect is shown in Figure 1. The railway with defect was cut into 10 mm size using water-jet cutter technology. This cutting method was chosen because it does not involve heat during its operation. The cut pieces were prepared for different microstructural analysis. The microstructural analysis involved the scanning electron microscopy (SEM), optical microscopy and the Vickers hardness test. Four samples were extracted from different location of the defect (see Figure 2). The four specimens were extracted from the beginning, middle and the end of defect with the purpose of performing comparative analysis. It should be noted that there was no particular procedure used in selecting the specimens’ location.
Figure 2. Specimens extracted from different defect locations.

The specimens were further cut horizontally at 3 mm from the top surface of the affected area. This depth was selected with the assumption that it will give enough information during analysis. The optical microscopy analysis specimens were mounted in the raisin for easier handling.

3. Results

3.1. Microstructural analysis

The microstructural analysis was performed in different parts of the specimens. The first analysis was performed 1 mm from the top surface of the specimens. The brown surface observed from all the figures is the rust on the surface of the specimens. The light brown surface is observed from different specimens with white traces in between. This kind of structure is known as the decarburized area (reduced carbon content) [15-16]. The microstructural analysis was also performed at 2 mm from the top surface of the specimens to achieve Figure 3. The microstructure below the decarburized region seem to be darker compared to the decarburized region and this is due to lower decarburization in this region. The microstructure captured 3mm from the top surface is shown in Figure 4. The microstructure extracted from this region is darker compared to the region above them. This is an
indication of higher carbon concentration. This then suggests that there was no enough temperature in this region for the decarburization to take place in this region.

![Microstructure](image1.png)

**Figure 3.** Microstructure near the top surface of the specimens.

3.2. Chemical composition
The chemical composition analysis of specimens cut from different locations of the railway piece with defect was performed. Table 1 shows the chemical composition of the four specimens from different locations of the defected railway piece. The specimens cut from the beginning of the defect has higher carbon content and manganese content compared to specimens from other sections of the defect. The reduction of carbon content indicates the extent of decarburization occurrence in each specimen. The two elements are a point of focus due to the fact that they play a major role towards the mechanical properties of the railway [13-17].

3.3. Vickers Hardness
The four specimens from different locations of the defected railway were prepared for the Vickers hardness test. Table 2 shows the results for the hardness tests performed in different locations of the specimens. Three tests were performed in each specimens starting with 1 mm from the top surface of each specimen. The second and third tests were performed 2 and 3 mm from the top surface of each specimen. It should be noted that tests were repeated four times for each depth so as to get the average values corresponding to each depth. The values recorded on Table 2 are the average values for each depth. The higher hardness was observed from the specimen that was extracted from the beginning of
the defect. The lowest hardness was observed from the specimens which were extracted from the middle of the defected railway. This behaviour is similar to the behaviour observed through chemical composition analysis. There is about 17% hardness drop between the first specimen, second and the third specimen while there is an approximate 16% gain in hardness value.

Figure 4. Microstructure from the middle of the specimens.

Table 1. Chemical composition of defected railway (mass%).

| Sample number | C   | Si  | Mn  | P    | S    | Cr   | Cu   |
|---------------|-----|-----|-----|------|------|------|------|
| 1             | 0.520| 0.185| 0.710| 0.0098| 0.014| 0.0050| 0.0049|
| 2             | 0.513| 0.173| 0.705| 0.0094| 0.025| 0.0047| 0.0043|
| 3             | 0.513| 0.169| 0.705| 0.0094| 0.015| 0.0047| 0.0041|
| 4             | 0.510| 0.167| 0.700| 0.0087| 0.019| 0.0051| 0.0041|
Table 2. Vickers hardness results (HV 10).

| Sample number | 1 mm   | 2 mm   | 3 mm   | Average |
|---------------|--------|--------|--------|---------|
| 1             | 266.5  | 262.5  | 264.5  | 264.5   |
| 2             | 221.5  | 219.5  | 218.5  | 219.8   |
| 3             | 219.5  | 217.5  | 220.5  | 219.2   |
| 4             | 261.5  | 259.5  | 257.5  | 259.5   |

4. Conclusion

The damaged rail tracks were microstructurally analysed using the microstructural analysis equipment. The steel rail material characterisation revealed the defects occurring at the rail tracks are caused by the decarburization. Decarburization obviously contributes towards the weakening of steel which then reduces wear resistance, reduces strength, enabling fatigue failures to occur more easily and increased rate of crack growth which affect their service life. All these factors are directly related to the hardness of the material. This decarburization is caused by the friction of the train wheel and the surface of the railway. The spinning might be caused by the irregularity of the railway network which might be resulting from number of factors. It has become clear that the South African conditions have not contributed to this kind of failure since this failure is caused by high temperatures.

Acknowledgements

The authors would like to thank Mr G Koopman and the laboratory technicians of Cape Peninsula University of Technology for their technical assistance in this study.

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