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Railway turnout failure mode analysis

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Abstract

A railway turnout, switch or set of points is a mechanical installation enabling railway trains to be guided from one track to another, such as at a railway junction, or where a spur or siding branches off. The turnout consists of the pair of linked tapering rails, known as points, lying between the diverging outer rails. A section of New South Wales' railways rail turnout was removed, since testing revealed that it had become defective and no longer fit-for-purpose. University of Wollongong was commissioned to investigate the failure mode(s) of the track section, and to provide a detailed report on the material composition, heat treatment, surface finish, wear and any material defects. since the turnout is over 25 years old, there are no test certificates or other quality assurance documents available for review. A literature search into turnout construction methods has shown that the Australian Standard AS 1085.21:2014 'Railway Track Material - Turnouts, Switches and Crossings' specifies that the turnout be made from cast high manganese steel. Manganese steel has the propensity to work harden rapidly over time. The turnout section of railway track was first cleaned and prepared for sampling. The head of the beam was cleaned with 'Penetrene' fluid and 'Scotch Bright' type scourers, until the rust and grime had been stripped back to reveal the clean metal below. The surface was then inspected for wear, damage and any adverse anomalies associated with the manufacturing process. Once inspected, the rail section was marked out for the cutting of samples. Samples were taken from strategic places along the beam including the head, web and in the convergence where the fracture was observed. Sample material was extracted from the turnout using the water jet cutting process. These samples were then prepared for metallographic microscopy, where inspections of the damaged areas were conducted and an assessment made to determine the cause of failure. Two different modes of failure were observed, namely: work hardening of the top face of the rail head resulting in spallation of the surface finish; high stress concentration from loading in the convergence of the turnout giving rise to fatigue, resulting in a partial fracture of the local area.

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Railway Turnout Failure Mode Analysis

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Abstract: *A railway turnout, switch or set of points is a mechanical installation enabling railway trains to be guided from one track to another, such as at a railway junction, or where a spur or siding branches off. The turnout consists of the pair of linked tapering rails, known as points, lying between the diverging outer rails. A section of New South Wales' railways rail turnout was removed, since testing revealed that it had become defective and no longer fit-for-purpose. The University of Wollongong was commissioned to investigate the failure mode(s) of the track section, and to provide a detailed report on the material composition, heat treatment, surface finish, wear and any material defects. Since the turnout is over 25 years old, there are no test certificates or other quality assurance documents available for review. A literature search into turnout construction methods has shown that the Australian Standard AS 1085.21:2014 'Railway Track Material - Turnouts, Switches and Crossings' specifies that the turnout be made from cast high manganese steel. Manganese steel has the propensity to work harden rapidly over time. The turnout section of railway track was first cleaned and prepared for sampling. The head of the beam was cleaned with 'Penetrene' fluid and 'Scotch Bright' type scourers, until the rust and grime had been stripped back to reveal the clean metal below. The surface was then inspected for wear, damage and any adverse anomalies associated with the manufacturing process. Once inspected, the rail section was marked out for the cutting of samples. Samples were taken from strategic places along the beam including the head, web and in the convergence where the fracture was observed. Sample material was extracted from the turnout using the water jet cutting process. These samples were then prepared for metallographic microscopy, where inspections of the damaged areas were conducted and an assessment made to determine the cause of failure. Two different modes of failure were observed, namely: work hardening of the top face of the rail head resulting in spallation of the surface finish; high stress concentration from loading in the convergence of the turnout giving rise to fatigue, resulting in a partial fracture of the local area.*

Keywords: *Railway track material, railway turnout, cast high manganese steel, metallography, failure mode analysis.*

1. INTRODUCTION

A railway turnout, switch or set of points is a mechanical installation enabling railway trains to be guided from one track to another, such as at a railway junction, or where a spur or siding branches off. The turnout consists of the pair of linked tapering rails, known as points, lying between the diverging outer rails. Turnouts are made from cast high manganese steel whose microstructure consists of manganese austenite, alloyed cementite $(Fe,Mn)_3C$, phosphorus eutectic and non-metallic inclusions [1].

A section of New South Wales' railways rail turnout was removed, since testing revealed that it had become defective and no longer fit-for-purpose (see Photo 1 in Appendix). The University of Wollongong was commissioned to investigate the failure mode of the track section, and to provide a detailed report on the material composition, heat treatment, surface finish, wear and any material defects [2]. Since the turnout is over 25 years old, there are no test certificates or other quality assurance documents available for review.

After cleaning, an initial inspection revealed the following two modes of failure present:

- Work hardening of the top face of the rail head resulting in surface spallation (see Photo 2).
- Stress concentration due to loading in the convergence of the turnout, initiating fatigue and resulting in a partial fracture of the local area (see Photos 3 and 4).

2. EXPERIMENTAL METHODS

2.1. Experimental Material

Since the turnout is over 25 years old, there are no test certificates or other quality assurance documents available for review. The Australian Standard for the construction of turnouts, switches and crossings [3] stipulates that the convergent insert be produced from cast high manganese steel. Manganese steel has the propensity to work harden rapidly over time. For this reason, all care is taken to reduce points of concentrated loading. Furthermore, the work hardening property also means that any machining work post-utilisation becomes very difficult. The chemical composition limits [4] for the manganese steel are specified in Table 1 below.

Table 1 Chemical composition for turnouts, points and crossing structures [4]

C (wt%)	**Mn (wt%)**	**Si (wt%)**	**Cr (wt%)**	**Mo (wt%)**	**V (wt%)**	**Al (wt%)**	**P (wt%)**	**S (wt%)**
1.05-1.15	11.5-14.0	≤ 0.65	≤ 0.5	≤ 0.5	≤ 0.5	≤ 0.05	≤ 0.03	≤ 0.03

2.2. Sample Preparation

The first task was to clean the turnout section of railway track and prepare it for sampling. The head of the beam was cleaned with 'Penetrene' fluid and 'Scotch Bright' type scourers, until the rust and grime had been stripped back to reveal the clean metal below (see Photo 1). The surface was then inspected for wear, damage and any adverse anomalies associated with the manufacturing process.

Once inspected, the rail section was marked out for the cutting of samples. Samples were taken from strategic places along the beam including the head, web and in the convergence where the fracture was observed. Sample material was extracted from the turnout using the water jet cutting process. This process was utilised as previous attempts to cut the material using traditional methods were unsuccessful owing to its work-hardened nature. The resulting samples were inspected for suitability and then trimmed down to manageable sizes for analysis. These samples were then prepared in the metallography laboratory for metallographic microscopy, by individually polishing and etching each one.

2.3. Sample Analysis

The samples which were analysed are tabulated below.

Table 2 Summary of samples analysed

Sample	**Description**	**Analysis**
#1	Turnout convergent root	Fracture examined for failure due to potential cyclic loading / fatigue
#2	Cross-section focusing on the spalled surface	Section analysed using both inspection by microscopy and hardness testing method (Vickers)
#3	Cross-section and working surface focusing on the spalled surface	Sections analysed using both inspection by microscopy and hardness testing method (Vickers)
#7	Working surface polished and etched	Surface analysed using stereo microscopy method

2.3.1. Sample #1

The root of the turnout was removed using a wire-cutting EDM method. The fracture (encapsulated within the sample) was next separated by mechanical means into manageable fragments. The fragments were then chemically cleaned and reviewed using stereo microscopy, where portions of the sample were photographed as points of interest arose.

2.3.2. Sample #2

A cross-sectional sliver taken from the first eight millimetres of the turnout working surface was analysed, focusing on the substructure of the working surface itself. The sample was examined under a stereo microscope for any unusual features. Vickers hardness testing was conducted as a function of depth using a 100g indenter.

2.3.3. Sample #3

Both cross-sectional sliver and working surface samples were taken from the first eight millimetres of the turnout working surface and analysed, focusing on the substructure of the working surface itself. The samples were examined under a stereo microscope for any unusual features. Vickers hardness testing was conducted on both as a function of depth using a 100g indenter. Hardness was also tested in an average location within each relevant region, namely: manganese steel, weld metal and carbon steel.

2.3.4. Sample #7

A cross-sectional sliver taken from the first eight millimetres of the turnout working surface was analysed, focusing on the substructure of the working surface itself. The sample was examined under a stereo microscope for any unusual features.

3. EXAMINATION AND FINDINGS

3.1. Sample #1

Within the fractured region a number of anomalies were detected, namely:

- A spheroidal inclusion ‘white’ in colour and ‘marble-like’ in texture (see Photos 5 and 6).
- A ‘wave-like’ structure akin to ratchet marks, suggesting that the damage was progressive and over a long period (see Photo 7).
- Minute spheroidal inclusions ‘black’ in colour and ‘coal-like’ in texture (see Photo 8).
- Secondary cracking not far from the primary fracture zone (see Photo 9).
- Surface cracking as seen on the inner radius of the turnout convergence. The cracking appears to follow the intergranular formation of the material itself (see Photo 10).

It is therefore apparent that the turnout contained a manufacturing defect, predisposing the product to eventual fatigue failure.

3.2. Sample #2

The major features to note were as follows:

- Heavily deformed and fractured/or cracked microstructure under the working surface. The Vickers hardness results show this region to be extremely hard. There has been a work-hardening process by way of the large amount of rail traffic. This has led to the surface structure hardening to the point of brittleness, resulting in the subsequent micro-fracturing of the structure (see Photo 11).

- Deeper internal cracking of the microstructure appears to follow the grain boundaries.
- The microstructure has a 'cloudy' appearance in places and exhibits a large grain structure.

The sample was tested for hardness using the Vickers method. Figure 1 illustrates the results from the working surface of the specimen down to a depth of 5.5mm.

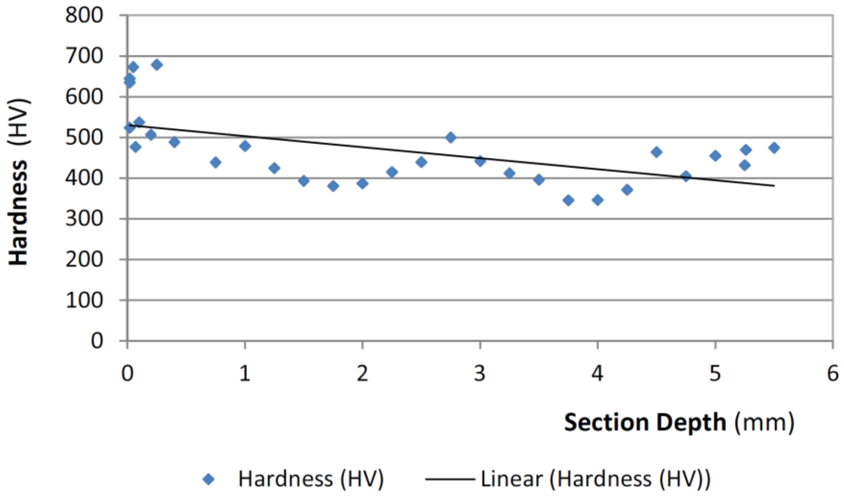

Figure 1 – Vickers hardness depth profile for sample #2.

3.3. Sample #3

The major features to note were as follows:

- 'Cloudy' appearance to the microstructure.
- Micro-cracking mostly along the grain boundaries.
- Fracturing of the microstructure below the spallation regions.
- Presence of 'dendritic' cast structure within grains in the body of the material (see Photo 12).

This sample was also tested for hardness using the Vickers method with a 100g indenter. Figure 2 illustrates the results from the manganese steel cross-section of the specimen down to the depth described.

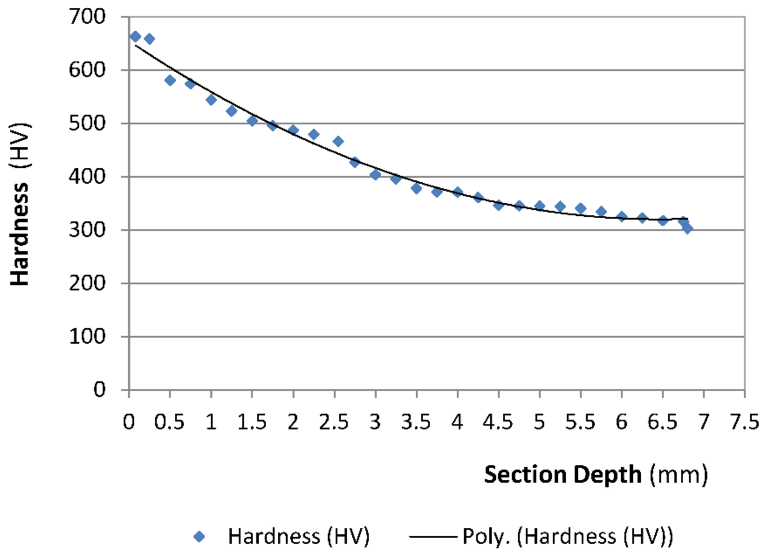

Figure 2 – Vickers hardness depth profile for sample #3 (manganese steel cross-section).

The hardness value appears to decrease exponentially as the sample is examined further away from the working surface. As mentioned previously, manganese steel has a propensity to work harden very rapidly, as demonstrated by these results.

Figure 3 shows the results from hardness testing of the polished working surface of the specimen to the depth described. This trimetal region consists of manganese steel, weld metal and carbon steel.

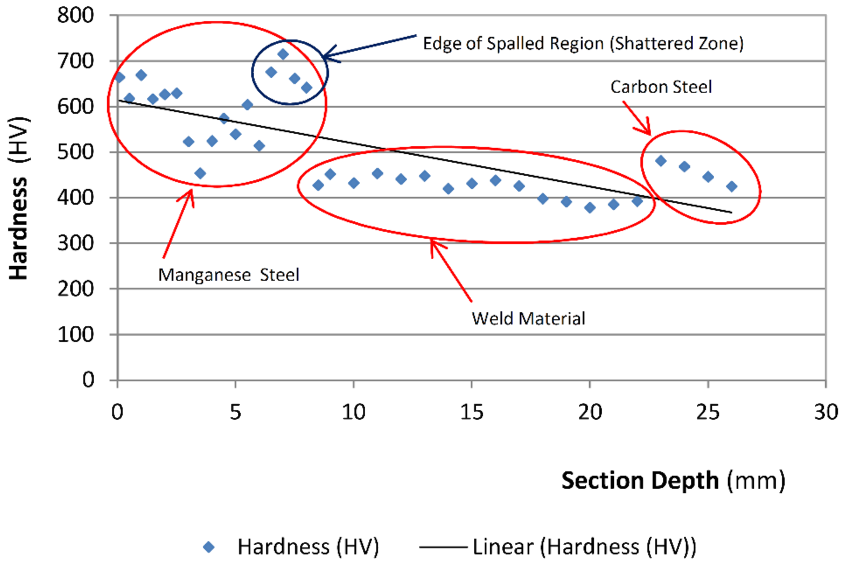

Figure 3 – Vickers hardness depth profile for sample #3 (trimetal surface material).

The material used in the weld metal is very bright in lustre and exhibits a fine granular microstructure. It is thought that the weld metal contains alumina as a result of the Thermit welding process used. Optical Emission Spectroscopy (OES) is recommended to investigate this further. OES is a proven and widely used analytical technique for determining the elemental composition of a broad range of metals.

Figure 4 shows the working surface hardness test results at an average location for each zone in the trimetal region.

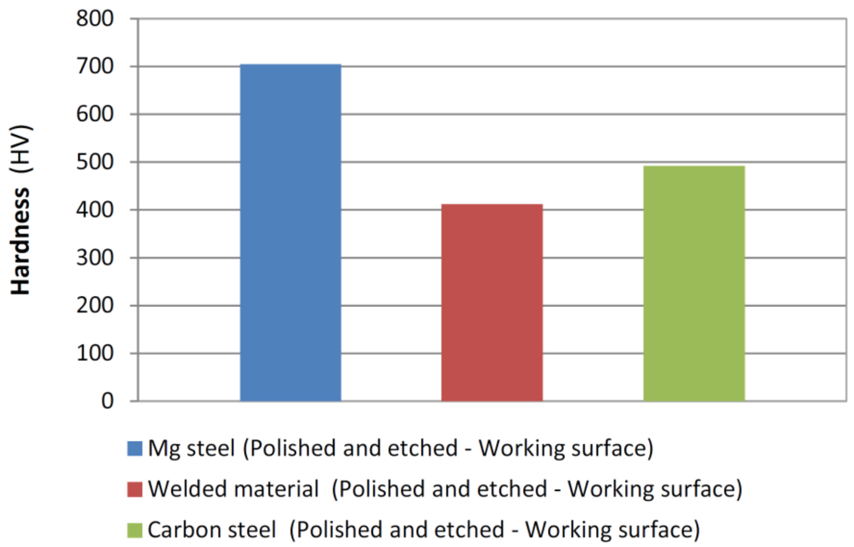

Figure 4 – Working surface Vickers hardness test results for sample #3 (trimetal average locations).

3.4. Sample #7

The major features to note from the microscopical examination were as follows:

- Large grain structure with what appear to be carbide inclusions (see Photo 13).
- Fracturing of the microstructure below the working surface (see Photo 14).
- Cracking along grain boundaries.
- Foreign inclusions which appear to be ‘black’ in colour with a blocky ‘cubic’ morphology.

All of the stereo microscopy photographs taken in this project may be found online in a Dropbox account [5].

4. DISCUSSION AND RECOMMENDATIONS

A railway turnout has been examined for its mode of failure and to determine an appropriate course of action when this fault is found in the field. The turnout has cracked within the convergence where the two rails meet. The turnout possessed a manufacturing defect exacerbating a high stress concentration within the convergence, resulting in fatigue failure. The sample shows a lack of burr removal during the dressing of the final product, which is the most likely cause of the stress concentration.

The extreme nature of the degradation by way of spallation from the working surface of the rail head is attributed to exposure to high loading cycles over a long period of time. This has led to a hardening and consequent shattering of the microstructure closest to the working surface, resulting in the observed spallation.

A potential ’field-fix’ solution to the first mode of failure is as follows. The fracture would need to be examined from both the top and the bottom aspects of the site. This may require the excavation of an undetermined amount of ballast in order to gain access below the fracture zone. Once the site has been declared suitable for field repairs, the horizontal surfaces should be cleaned with a linishing belt. Magnetic particle testing would then be carried out to determine the extent of the fracture, thus locating the point of propagation. At this point, to stress relieve the fracture site, a hole is to be drilled through the full thickness of the material encapsulating the point of convergence within the fracture site. The turnout root radius should then be deburred to ensure that any obvious sources of stress concentration are removed. The fault line is then notched and prepared for welding. Finally, the fracture is fused using an appropriate welding technique and the weld bead ground/finished to the original surface level. Non-destructive testing (NDT) techniques of the affected area should be employed to ensure that the repair process has been successful.

Regarding the second mode of failure, a potential ‘field-fix’ solution is as follows. As the hardness decreases towards normal values after 8 to 10 millimetres from the track working surface, it is recommended that the top of the rail head be ground down several millimetres below the work hardened zone and reclaimed with an appropriate weld fill material, then ground to achieve an industry standard profile and surface finish. The finished surface should be examined using NDT techniques to verify the quality of the rail head reclamation process.

5. REFERENCES

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6. APPENDIX – STEREO MICROSCOPY PHOTOGRAPHS

Photo 1 – Rail head cleaned and ready for inspection.

Photo 2 – Close-up of major spallation site.

Photo 3 – Fracture site in rail convergence.

Photo 4 – Fracture site as viewed from below.

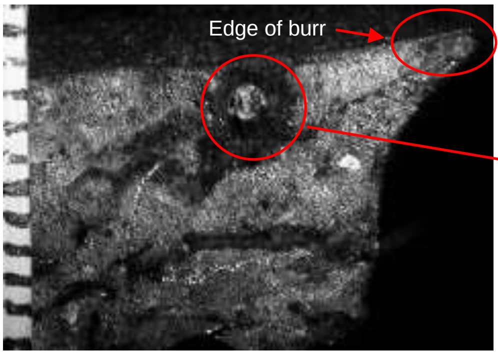

Photo 5 – Inclusion within casting (7x mag).

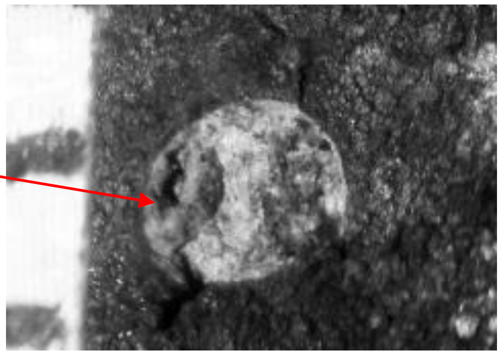

Photo 6 – Inclusion within casting (40x mag).

Photo 7 – Potential ratcheting (14x mag).

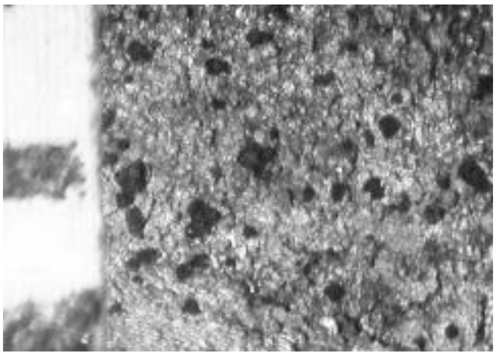

Photo 8 – Foreign inclusions at fracture site (45x mag).

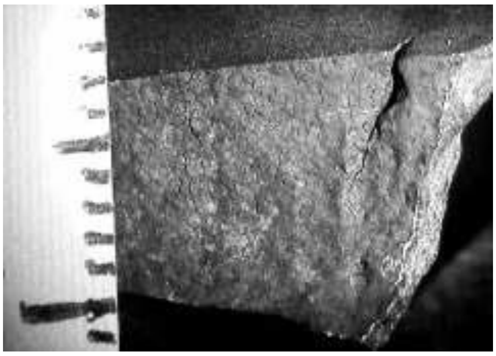

Photo 9 – Secondary cracking (7x mag).

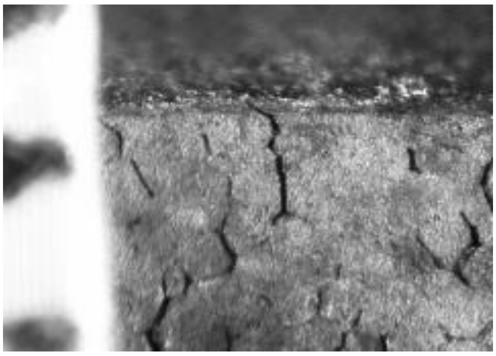

Photo 10 – Root radial surface (40x mag).

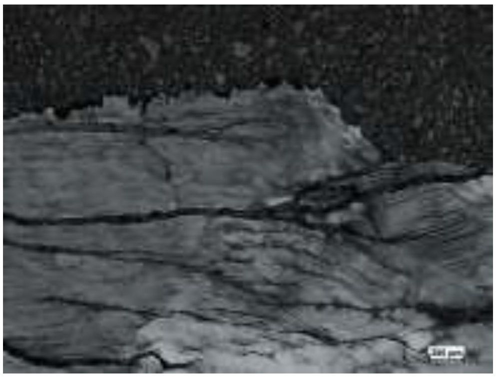

Photo 11 – Heavily deformed and cracked surface region.

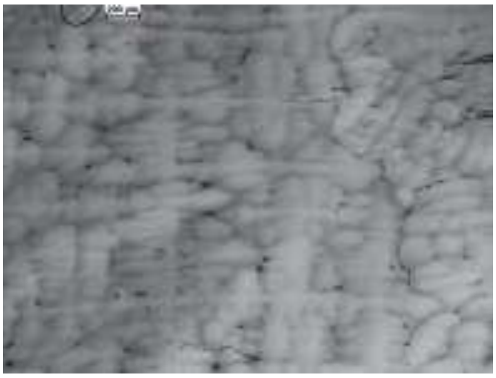

Photo 12 – Dendritic structure within grains.

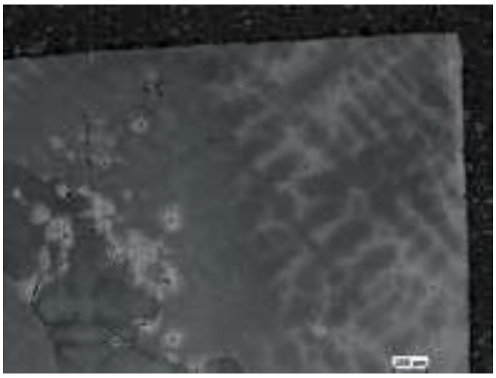

Photo 13 – Large grain with inclusions.

Photo 14 – Subsurface cracking.