**Annex A**

Chain manufacturer's chain inspection certificate

Image courtesy of [Fasing S.A.](#)

INTEGRATED QUALITY AND ENVIRONMENT MANAGEMENT SYSTEM

SUPERVISED BY TÜV NORD Polska

PN-EN ISO 9001:2009: AC090 100/1267/64/2015
PN-EN ISO 14001:2005: AC090 104/1267/64/2015

GRUPA KAPITAŁOWA

# FASING S.A.


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SERWIS tel. +48 32 735 00 00 w. 467, 468


| INSPECTION CERTIFICATE No.: | E-118/2019 | "Type 3.1" acc. to PN-EN 10204 |
|---|---|---|

| Chain / Type (Designation) | 32 x 96 | 8 | 2 strands x 50 m | 63200081 |
|---|---|---|---|---|
| | ( size | grade | other | catalogue No.) |
| produced acc. to | EN 818-2 | | - | ASTM A 391/A |
| | ( standard | | technical requirements | other ) |

| | | | |
|---|---|---|---|
| Date of receipt: | 2019-04-23 | Ordering party: | George Taylor & Co., UK |
| Producer/ Supplier: | Mining Tools and Equipment Factories Capital Group FASING Plc. | User: | - |
| | | Purchase Orde No.: | 76570 |
| Quantity supplied: | 100 m | Contract No.: | - |
| Production Order No.: | DE1/112/2019 | Purchase Ordedate: | 2019-04-12 |

| Item | Tested parameter or measured quantity | | Symbol | Unit of measurement | Required value | Measured value (Sample No. 1) |
|---|---|---|---|---|---|---|
| 1 | Nominal diameter of the round link | | $d_m$ | mm | 32±1,6 | 32,7 |
| 2 | Thickness of the flat link | | - | mm | - | - |
| 3 | Weld diameter | | $d_s$ | mm | max.37,0 | 33,2 |
| 4 | Weld width | | - | mm | - | - |
| 5 | Pitch | round link | p | mm | 96±2,9 | 96,1 |
| | | flat link | - | mm | - | - |
| 6 | Inside width | round link | $w_1$ | mm | min.41,6 | 46,4 |
| | | flat link | - | mm | - | - |
| 7 | Outside width | round link | $w_2$ | mm | max.118 | 111,2 |
| | | flat link | - | mm | - | - |
| 8 | Crown radius | | r | mm | - | - |
| 9 | Length of 11 links | | l | mm | 1056+5,3 | 1057,1 |
| 10 | Manufacture proof force | | MPF | kN | 804 | 804 |
| 11 | Breaking Force | | Fz/BF | kN | min.1290 | 1480 |
| 11a | ~~Working Force~~/Working Load Limit | | ~~WF~~/ WLL | ~~kN~~/ t | max.31,5 | 31,5 |
| 12 | Break place: **L**- leg; **C** - crown; **W** - weld | | | | | C |
| 13 | Elongation under test force | | Ep | % | - | - |
| 14 | Elongation at fracture | | Ek | % | min20 | 38,5 |
| 15 | Deflection | | f | mm | 26 | 26 |
| 16 | Charpy-V-test | | KV | J | - | - |
| 17 | Hardness | | UNIT * HRC, HBW, HV | | - | - |
| 18 | Fatigue resistance | | Lower load $F_u$ : - [kN] Upper load $F_o$ : - [kN] Frequency of load changes N : - [Hz] | | | |
| | | | T/N | cycles | - | - |
| 19 | Break place: **L**- leg; **C** - crown; **W** - weld | | | | | - |

| Chemical analysis of the material acc. to DIN 17115 / ~~PN-92/H-93028~~ | Heat No.: 221071 | C | Si | Mn | P | S | Cr | Mo | Ni | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| Chemical composition in percentages by weight | | 0,211 | 0,216 | 0,215 | 0,0154 | 0,0064 | 0,567 | 0,252 | 0,510 | 0,0281 |

Marking: H52-8 3/19

Remarks: Black painted ; 1194 kg

* delete as appropriate

| Quality Control | Department Manager | Management System Department |
|---|---|---|
| [redacted] | [redacted] | [redacted] |
| stamp and signature | stamp and signature | stamp and signature |

**Annex B**

Failure of chain link investigation on board *Cornishman* report no. 2021-5360

Image courtesy of Det Norske Veritas

FAILURE OF CHAIN LINK ONBOARD CORNISHMAN

# Failure investigation

## Marine Accident Investigation Branch

**Report No.:** 2021-5360, Rev. 0
**Document No.:** 1248316
**Date:** 2021-12-14

| | | |
|---|---|---|
| Project name: | Failure of chain link onboard Cornishman | DNV AS Oil & Gas |
| Report title: | Failure investigation | Materials & Testing - Bergen |
| Customer: | Marine Accident Investigation Branch, 1st Floor Spring Place | Thormøhlensgt. 49A |
| | 05 Commercial Road | 5006 Bergen |
| | O15 1GH Southampton | Norway |
| | United Kingdom | Tel: +47 55 94 36 00 |
| | | 945 748 931 |
| Customer contact: | [redacted] | |
| Date of issue: | 2021-12-14 | |
| Project No.: | 10299927 | |
| Organisation unit: | Materials & Testing - Bergen | |
| Report No.: | 2021-5360, Rev.0 | |
| Document No.: | 1248316 | |

Applicable contract(s) governing the provision of this Report:
Department for Transport: Award letter, dated 2021-06-02.
PO8000211980, PO8000213253, PO8000213727, PO8000214972

Objective:

The main objective of the performed failure investigation has been to characterize the fracture and identify direct and underlying causes.

| Prepared by: | Verified by: | Approved by: |
|---|---|---|
| [redacted] | | |



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*Specify distribution: DNV

Keywords:
Lifting chain; Grade 8

| Rev. No. | Date | Reason for Issue | Prepared by | Verified by | Approved by |
|---|---|---|---|---|---|
| A | 2021-09-30 | Draft version for client comments | [redacted] | | |
| B | 2021-11-23 | Tensile testing included, discussion, conclusion and recommendations updated | | | |
| 0 | 2021-12-14 | First issue | | | |

DNV

## Table of contents

Image courtesy of Det Norske Veritas

# 1 EXECUTIVE SUMMARY

DNV AS, Materials Bergen (DNV) has been requested by Marine Accident Investigation Branch (MAIB) to perform a failure investigation of a fractured chain.

The chain has been used as part of a quick release system for trawl gear onboard the trawler Cornishman. One of the chain links in the quick release system on the port side of the vessel fractured, causing the trawl fishing gear to fall down.

## 1.1 Conclusions

Based on the performed examination, the following is concluded:

- Based on comparison between wear marks on the fractured chain and the corresponding chain on the starboard side, the fractured link is assumed to have been positioned at the derrick head pin, on the side towards the steel wire rope side, meaning that bending of the chain link has occurred.
- A large number of cracks and crack-like indications have been detected, both in the portside chain that fractured, but also in the starboard chain used in parallel to the portside one. The large number of cracks are believed to be related to environmentally induced cracking, most likely related to hydrogen embrittlement. This has induced crack growth in multiple positions.
- The underlying cause of fracture is a high hardness and low ductility chain material in a corrosive environment (giving hydrogen formation), in combination with tensile stress, giving material embrittlement. Hydrogen introduced during the steel chain manufacturing process may also have contributed to the material embrittlement.
- The mechanical testing confirms very low ductility of the material, (yield to tensile strength ratio of 0.99 and 0.998 for the fractured chain and the reference chain, respectively). Low ductility increases the susceptibility to environmentally induced cracking.
- Generally, a Grade 8 chain is considered by the industry to be appropriate for lifting applications in marine environments. However, the Grade 8 quality requirements do not include a maximum hardness / maximum tensile strength requirement or specifications for ductility. Materials with hardness higher than 350 HV10 should be considered susceptible to hydrogen embrittlement.
- Testing of chain segments has shown break load significantly below the requirement. This is not considered to be a direct cause of the failure, as no indication of overloading of the chain is found. However, this is an indication of variation in the material properties of the chain. The low obtained break load is believed to be caused by the low ductility.
- The high hardness, low ductility and low break load strength of the material indicate that the tempering process of the chain has not been successful. The deviation from the certificate values (both break load testing and manganese content), shows variation in the fabrication.

The performed examination has included examination of the fractured portside chain, the corresponding starboard side chain, and an unused reference chain, in addition to the derrick heads. The examination has comprised visual examination, MPI (wet-fluorescent magnetic particle inspection), material characterization and mechanical testing of all three chains and derrick heads, in addition to fractographic examination of the fractured chain link.

## 1.2 Recommendations

Generally, a Grade 8 chain is considered by the industry to be appropriate for lifting applications in marine environments. However, the Grade 8 quality requirements do not include a maximum hardness / maximum tensile requirement or requirements to ductility. Hence, additional requirements are included in several standards, especially for even higher strength steel chain, see discussion part.

Materials with hardness higher than 350 HV10 should be considered susceptible to hydrogen embrittlement and it should be considered good practice to limit the use of these high strength materials in critical lifting / load bearing applications in marine atmosphere and submerged applications. Post manufacturing baking to remove hydrogen introduced through the manufacturing process should also be considered good practice /8,11/.

Also, the Grade 8 quality requirements do not include requirements to ensure good ductility of the chain material, for instance yield to tensile strength ratio. The extremely high yield to tensile strength ratio is assumed to have large influence on the susceptibility of hydrogen-induced cracking and hence contribute to the failure. For a chain with a higher utilization, these properties could also have serious consequences in the form of premature fracture, as seen in the break load testing. Hence, measures should be taken to ensure increased ductility.

To prevent equivalent failures in similar applications in the future, the following is recommended:

- It is recommended to initiate actions with regard to qualification of the fabrication process, to ensure a consistent quality of lifting chain. The large variation in chain properties indicate variation in the fabrication.
- It is also recommended to include test scope and acceptance criteria for mechanical properties for chain material, that are suitable to avoid failure mechanisms as describe above. This should cover both hardness/strength and ductility.

A preventive measure could also be regular inspection of the chain. However, the effectiveness of this could be limited due to a rough and corroded surface where detection of cracks will be difficult and hence possible need for dismantling and cleaning. The short time in service for the examined chain also indicates rapid crack growth.

# 2 INTRODUCTION

DNV AS, Materials Bergen (DNV) has been requested by Marine Accident Investigation Branch (MAIB) to perform a failure investigation of a fractured chain.

The chain has been used as part of a quick release system onboard the trawler Cornishman. One of the chain links on the port side of the vessel fractured, causing the trawl fishing gear to fall down. The incident caused one fatality.

The incident occurred while the trawling system was not in use, however the weight of the system was supported by the quick release system.

## 2.1 Background

The principle of the quick release system is to release the trawl gear in an emergency, should the trawl gear cause the fishing vessel to become unstable. To achieve this, the trawl warp (a single wire that is attached to the towing bridle) is passed through a snatch block (or towing block), see an example of a similar system in Figure 2-1.

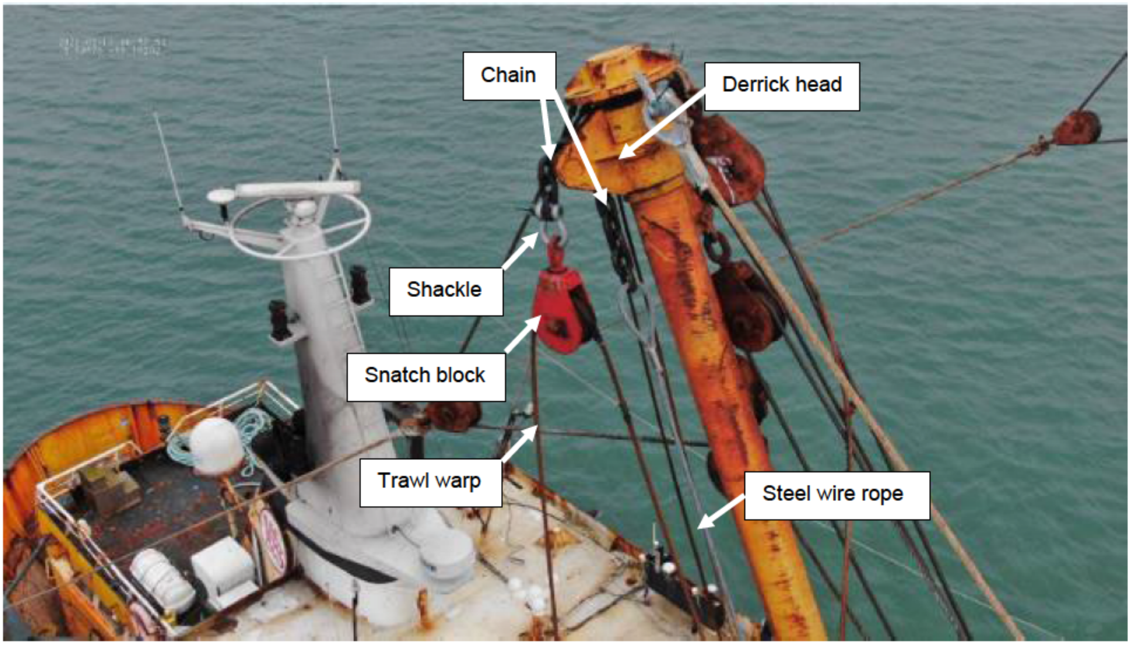



**Figure 2-1 Examples of quick release system similar to the one that failed. Image supplied by the client.**

The snatch block is suspended using a shackle on a chain that passes over a pin welded between cheek plates fitted to the derrick head. This chain failed.

The loading caused by towing the trawl along the seabed and lifting the trawl clear of the water is transmitted fully through the chain forming part of the quick release system. The Working Load Limit of the system is 8.4 tonnes.

The head of the derrick which supports the quick release chain has a limited degree of rotational freedom (ca. 60°) around the derrick allowing the lead of the snatch block and chain to move towards the load.

Similar systems are found on both sides of the vessel, and parts from both systems have been received for testing.

The chain is a 32 mm diameter grade 8 short link chain, and the received certificate is given in Appendix A. The certificate refers to the standards NS-EN ISO 818, Short link chain for lifting purposes – Safety – Part 2: Medium tolerance chain for chain slings - Grade 8 /1/ and ASTM A391, Standard Specification for Grade 80 Alloy Steel Chain /2/. The report has not assessed relevant requirements for the intended use.

In the chain certificate (given in Appendix A) the Measured breaking force is stated to be 1480 kN, which is 4.7 times the stated working load limit of 31.5 tons (equivalent to 314 kN). The minimum required breaking load is 1290 kN. The chain is also connected to a steel wire rope, with working load limit 8.4 tons. This steel wire rope is considered to be a weaker component compared to the chain.

The certificate is dated 2019-04-23. According to information from the client, the chains (both the starboard and the portside) has been in use from March 2020. i.e. approximately one year. The background for changing the chain at that time, and if the derrick heads were changed or refurbished at the same time is not known.

# 3 BASIS FOR WORK

An overview of the received parts is given in Table 3-1. The part ID's are given by the client.

**Table 3-1 Overview of received samples.**

| Part ID | Description |
|---|---|
| Part BJC/1 | Part of portside chain, connected to steel wire rope |
| Part BJC/2 | Unused section of chain |
| Part BJC/3 | Starboard chain |
| Part BJC/4 | Part of fractured link, portside chain |
| Part BJC/5 | Part of portside chain, towards trawl |
| MPH/CM/PORT/3 | Portside derrick head |
| MPH/CM/SB/1 | Starboard derrick head |

According to information from the client, the chain is bought in lengths of 8 meter and stored on a pallet in a store located around 2-300 meters from the sea. When a vessel asks for a replacement of the quick release gear, a length of chain is cut (10 - 13 links depending on the request) and then sent off to a contractor to prepare the quick release gear, by splicing the chain to the wire. The unused reference chain (Part BJC/2), has only been stored as described above.

## 3.1 Objective and scope of work

The main objective of the performed failure investigation has been to characterize the fracture and identify direct and underlying causes.

The performed examination has comprised:

- Review of relevant information
- Visual examination of all received parts
- NDT of all received chain links and derrick heads
- Material characterisation of single links and derrick heads:
    - Metallographic examination
    - Chemical analyses
    - Hardness testing
    - Estimation of tensile strength
    - Tensile testing (not derrick heads)
- Fractographic examination of fractured chain link
- Metallographic examination of fracture chain link
- Break load testing and visual examination of test samples

# 4 EXAMINATION AND CHARACTERISATION OF RECEIVED PARTS

## 4.1 Overview of received samples

Overview images showing the parts as received are given in Figure 4-1 to Figure 4-7. For all the chain samples, one of the ends were marked by DNV using a coloured plastic strip, to keep traceability of the two ends of each chain length. Different colours were used for the different samples.

**Figure 4-1 Sample BJC/1, part of portside chain, connected to steel wire rope. The upper image shows both chain and steel wire rope part, the lower image shows the chain at higher magnification.**

**Figure 4-2 Sample BJC/2, unused (reference) section of chain.**

**Figure 4-3 Sample BJC/3, starboard chain.**

Image courtesy of Det Norske Veritas


**Figure 4-4 Sample BJC/4, part of fractured link, portside chain. The letters A and B is used further for identification of the two fracture surfaces.**

**Figure 4-5 Sample BJC/5, part of portside chain, towards trawl.**

Figure 4-6 Sample MPH/CM/PORT/3 (PORT/3), portside derrick head.

Figure 4-7    Sample MPH/CM/SB/1 (SB/1), starboard derrick head.

Typical appearance of chain surfaces prior to any cleaning is shown in Figure 4-8. Only a limited visual examination was performed prior to cleaning, as the large amount of corrosion products on the link surfaces was considered to obscure most relevant observations.

**Figure 4-8 Typical appearance of chain surface prior to cleaning. Upper: BJC/3; Lower: BJC/5.**

Numbering of the single links (defined by DNV) are from the steel wire rope side, towards the trawl side, i.e. link 1 is connected to the steel wire rope while link 10 is connected to the shackle connected to the trawl system, see Figure 4-9. For the unused chain, the numbering is arbitrary.

Image courtesy of Det Norske Veritas


**Figure 4-9 Numbering of chain links.**

## 4.2 Overview of performed testing

An overview of the testing performed on the different samples are shown in Table 4-1.

**Table 4-1 Overview of performed testing for the different parts.**

| Part ID | Description | Details | Testing performed* |
|---|---|---|---|
| Part BJC/1 | Part of portside chain, connected to steel wire rope | Steel wire rope | None |
| | | Link 1-2-3 | MPI (wet-fluorescent magnetic particle inspection)<br>Visual examination |
| | | Link 4 | MPI<br>Visual examination<br>Tensile testing |
| | | Link 5 | MPI (wet-fluorescent magnetic particle inspection)<br>Visual examination<br>Material characterisation |
| Part BJC/2 | Unused section of chain** | Link – 1 – marked blue | MPI<br>Visual examination |
| | | Link 2-9 | MPI<br>Visual examination<br>Material characterisation (one link)<br>Tensile testing (one link) |
| Part BJC/3 | Starboard chain | Link 1 – marked green | MPI<br>Visual examination<br>Material characterisation |
| | | Link 2-9 | MPI<br>Visual examination |
| | | Link 10 | MPI<br>Visual examination |
| Part BJC/4 | Part of fractured link, portside chain | Link 6 | MPI<br>Visual examination<br>Material characterisation<br>Fractographic examination<br>Metallographic examination in initiation area |
| Part BJC/5 | Part of portside chain, towards trawl | Link 7 – marked orange | MPI<br>Visual examination |
| | | Link 8-9 | MPI<br>Visual examination |
| | | Link 10 | MPI<br>Visual examination<br>Material characterisation |
| MPH/CM/PORT/3 | Portside derrick head | Marked yellow | MPI<br>Visual examination<br>Material characterisation (cheek plate material) |
| MPH/CM/SB/1 | Starboard derrick head | No marking | MPI<br>Visual examination<br>Material characterisation (pin material) |

* Material characterisation includes metallographic examination, hardness testing, estimation of tensile strength and chemical analyses.

** Note that for the unused chain, the numbering of links is arbitrary.

A drawing showing the approximate position of the different samples taken for material characterisation of chain material is shown in Figure 4-10.

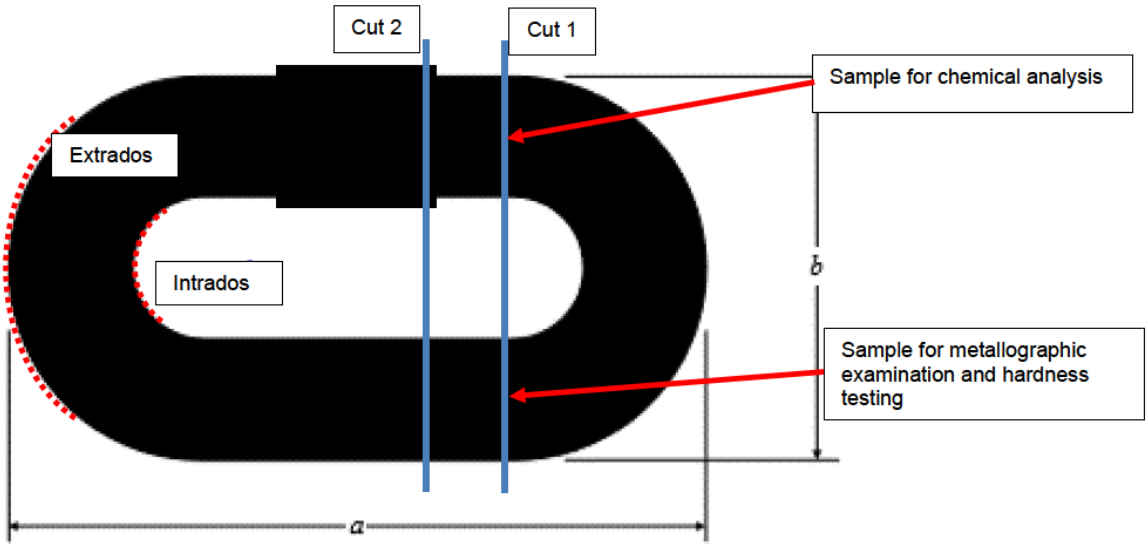



**Figure 4-10 Position of samples for testing. The two blue lines show the cutting positions. All testing (hardness, metallographic examination and chemical analysis) is performed on cut surface 1. The areas denoted extrados and intrados are shown in the drawing.**

## 4.3 Visual examination of chain samples

When received, the used chain samples had significant corrosion, and no apparent coating/paint. To remove loose corrosion products and possible remains of coating/paint, the chains were cleaned using Valhall CleanCons (diluted according to supplier's recommendations), an inhibited acid-based cleaning agent, and cleaned using high-pressure washer (water) afterwards. This was beneficial both for the visual examination, and a requirement in order to obtain good performance of MPI.

A summary of the observations made on the different chain links is given in Table 4-2. The table also includes reference to relevant images of the different chain links.

**Table 4-2 Overview of observations on the different chain links.**

| Part ID | Description | Link no. | Observations |
|---|---|---|---|
| Part BJC/1 | Part of portside chain, connected to steel wire rope | 1 | - Crack-like indications in both ends of the link<br>- The larger crack extends approximately 180° around the chain link circumference.<br>- Uneven surface in connection to the weld<br>- No significant wear/deformation marks<br>- See Figure 4-11 |
| | | 2 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- No significant wear/deformation marks.<br>- See Figure 4-12 |
| | | 3 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- No significant wear/deformation marks.<br>- See Figure 4-13 |
| | | 4 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- Some increased interlink wear towards link 5 is seen<br>- See Figure 4-14 |

| Part ID | Description | Link no. | Observations |
|---|---|---|---|
| | | 5 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- Some increased interlink wear is seen<br>- See Figure 4-15 |
| Part BJC/2 | Unused section of chain* | 1-9 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- Some asymmetric geometry<br>- Marking: “3/19” and “H52-8”, see Figure 4-16. This corresponds to the information about marking given in the certificate (Appendix A). |
| Part BJC/3 | Starboard chain | 1 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- No significant wear/deformation marks.<br>- See Figure 4-17 |
| | | 2 | - Crack-like indication towards link 3<br>- Uneven surface in connection to the weld<br>- No significant wear/deformation marks.<br>- See Figure 4-18 |
| | | 3 | - Crack-like indications in both ends of the link.<br>- The larger crack extends approximately 270° around the chain link circumference.<br>- Uneven surface in connection to the weld<br>- No significant wear/deformation marks.<br>- See Figure 4-19 |
| | | 4 | - Crack-like indications in both ends of the link, also one crack close to the weld.<br>- The larger crack extends approximately 360° around the chain link circumference.<br>- Uneven surface in connection to the weld<br>- No significant wear/deformation marks.<br>- See Figure 4-20 |
| | | 5 | - Crack-like indication towards link 4<br>- The larger crack extends approximately 180° around the chain link circumference.<br>- Uneven surface in connection to the weld<br>- No significant wear/deformation marks.<br>- See Figure 4-21 |
| | | 6 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- No significant wear/deformation marks, however an asymmetric geometry is seen.<br>- See Figure 4-22 |
| | | 7 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- Wear marks towards link 8, mainly on one side, towards both shoulders<br>- See Figure 4-23 |
| | | 8 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- Wear marks towards both sides, towards both shoulders<br>- See Figure 4-24 |
| | | 9 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- Significant wear marks towards both ends. Towards link 8, marks towards both shoulders, towards link 10, one main mark<br>- See Figure 4-25 |
| | | 10 | - Visual crack-like indications in one end of the link and on one leg<br>- Uneven surface in connection to the weld<br>- Significant wear mark in one end of the link<br>- Wear marks on side/shoulders<br>- See Figure 4-26 |
| Part BJC/4 | Part of fractured link, portside chain | 6 | See Paragraph 5.1 for visual examination |
| Part BJC/5 | Part of portside chain, towards trawl | 7 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- Wear mark in both ends of the link. Against link 8, there are wear marks towards both shoulders.<br>- See Figure 4-27 |

| Part ID | Description | Link no. | Observations |
|---|---|---|---|
| | | 8 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- Significant wear mark in both ends of the link. Against link 9, there are wear marks towards both shoulders.<br>- See Figure 4-28 |
| | | 9 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- Significant wear mark in both ends of the link. Against link 8, there are wear arks towards both shoulders.<br>- See Figure 4-29 |
| | | 10 | - No crack-like indications from visual inspection<br>- Uneven surface in connection to the weld<br>- Significant and asymmetric wear mark in both end of the link<br>- Wear marks on side/shoulders<br>- See Figure 4-30 |

* Note that for the unused chain, the numbering of links is arbitrary.

The most wear is seen towards the trawl end of the chains, probably due to more movement in these areas.

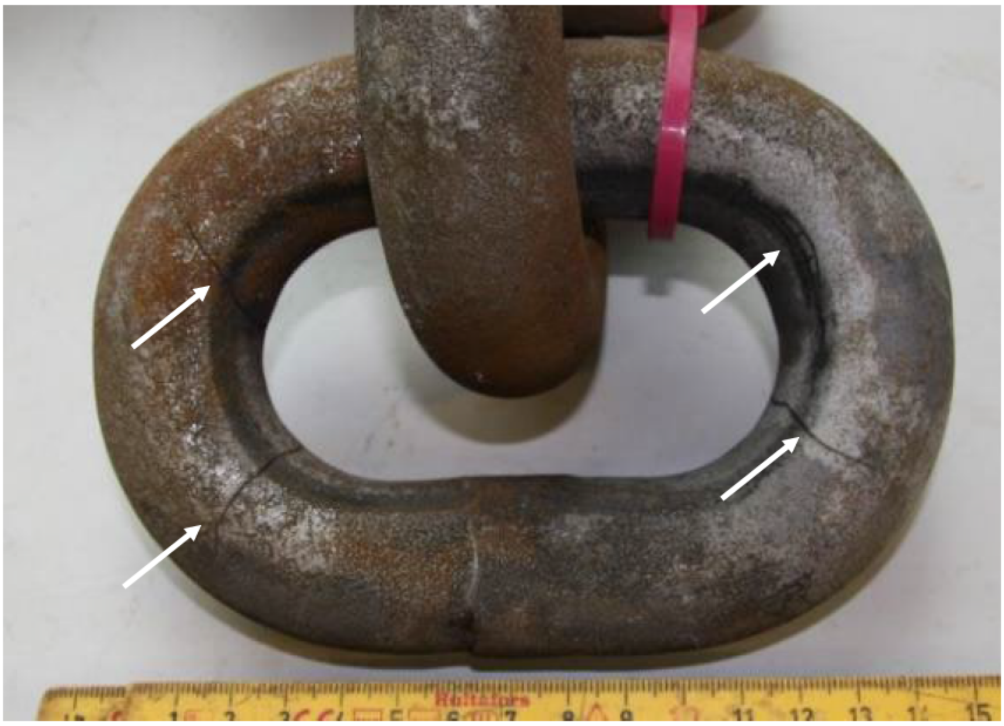


**Figure 4-11 BJC/1 – Link 1 after cleaning. Cracks are seen in four areas, indicated by arrows.**


**Figure 4-12 BJC/1 – Link 2 after cleaning. No crack-like indications.**


**Figure 4-13 BJC/1 – Link 3 after cleaning. No crack-like indications.**

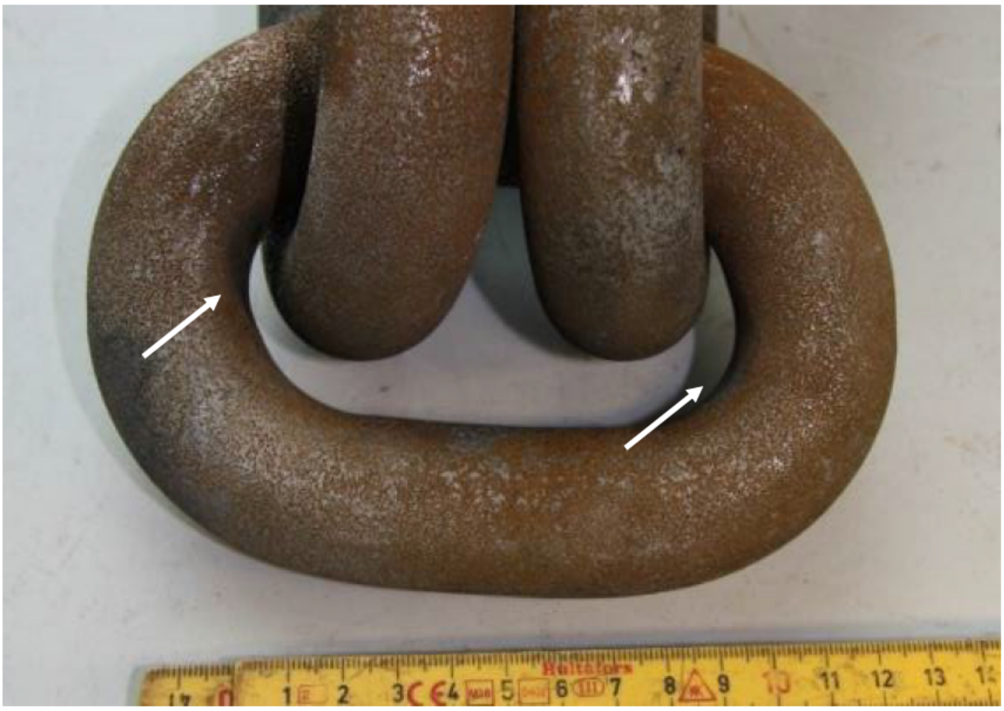



Figure 4-14 BJC/1 – Link 4 after cleaning. No crack-like indications. Some interlink wear seen, indicated by arrows.


Figure 4-15 BJC/1 – Link 5 after cleaning. No crack-like indications. Some interlink wear, indicated by arrows.

Figure 4-16 BJC/2 –Marking on unused chain link.

Figure 4-17 BJC/3 – Link 1 after cleaning. No crack-like indications.

Image courtesy of Det Norske Veritas


Figure 4-18 BJC/3 – Link 2 after cleaning. Possible crack-like indications, indicated by arrows.

Figure 4-19 BJC/3 – Link 3 after cleaning. Crack-like indications observed, indicated by arrows.

Figure 4-20 BJC/3 – Link 4 after cleaning. Crack-like indications are seen in both ends, as well as close to the weld, as indicated by arrows.

Image courtesy of [Det Norske Veritas]

Figure 4-21 BJC/3 – Link 5 after cleaning. Crack-like indication towards link 4 is indicated by arrows.

Figure 4-22 BJC/3 – Link 6 after cleaning. No crack-like indications, however some asymmetric geometry.

Figure 4-23 BJC/3 – Link 7 after cleaning. No crack-like indications, however wear/deformation marks towards link 8, indicated by arrows.

Figure 4-24 BJC/3 – Link 8 after cleaning. No crack-like indications, however significant wear/deformation in both the interlink areas.

Image courtesy of [Det Norske Veritas]

Figure 4-25 BJC/3 – Link 9 after cleaning. No crack-like indications, however significant wear/deformation of the interlink areas.

Figure 4-26 BJC/3 – Link 10 after cleaning. Crack-like indications are seen in one end of the link and on the leg of the link, significant interlink wear/deformation, in the other end, and wear marks on the side of the link, close to the crack. All are indicated by arrows.

DNV

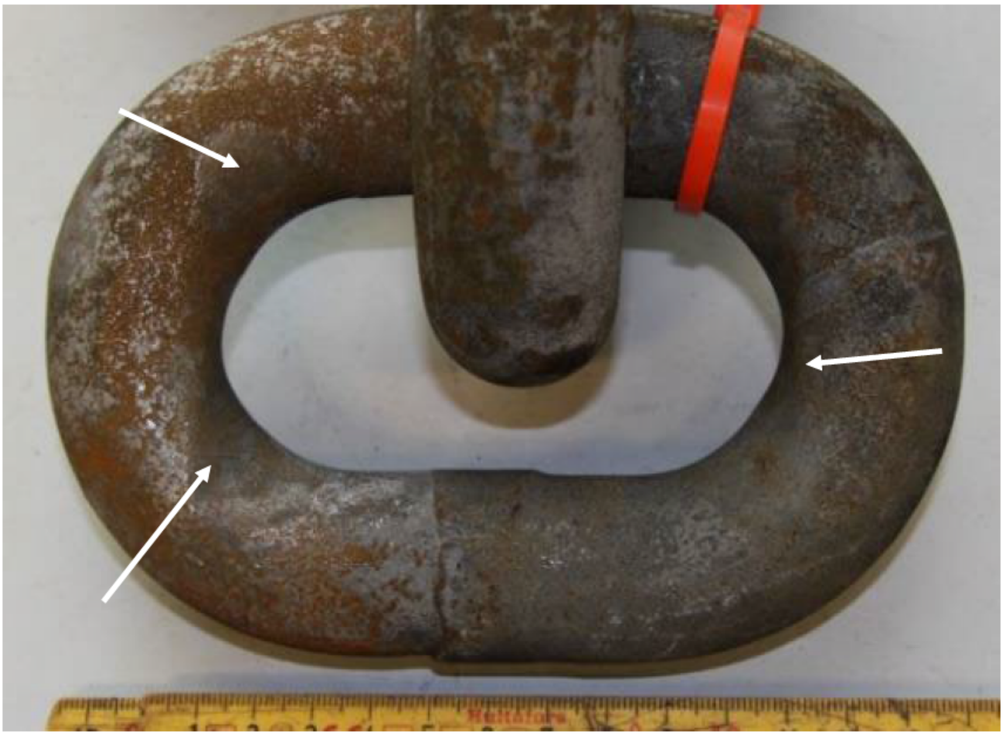


**Figure 4-27 BJC/5 – Link 7 after cleaning. No crack-like indications, however significant wear/deformation of the interlink areas.**

**Figure 4-28 BJC/5 – Link 8 after cleaning. Significant interlink wear/deformation, indicated by arrows. No crack-like indications.**

Image courtesy of [Det Norske Veritas]

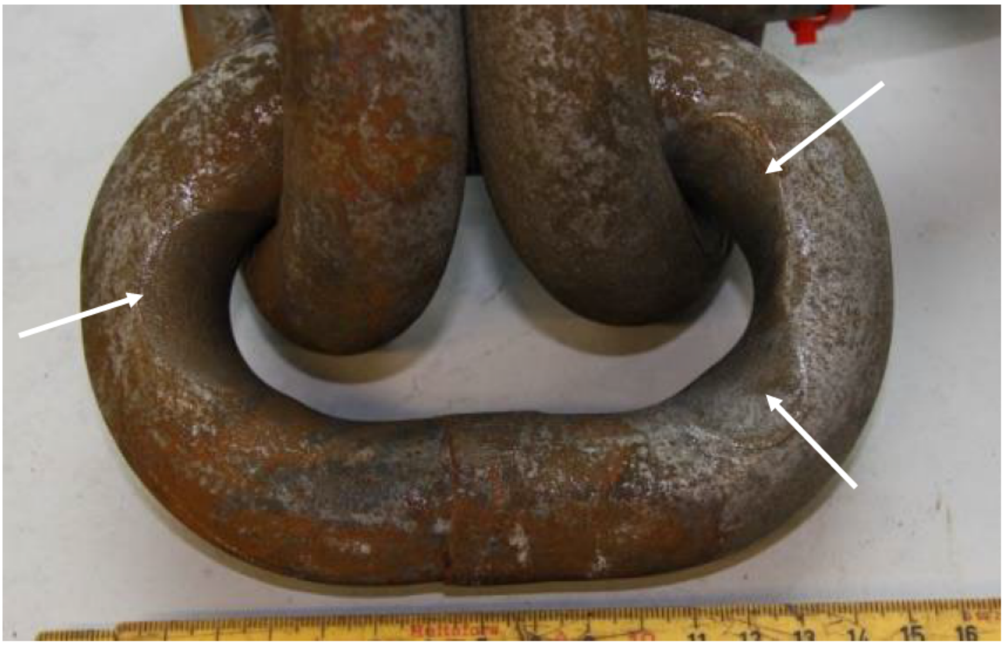


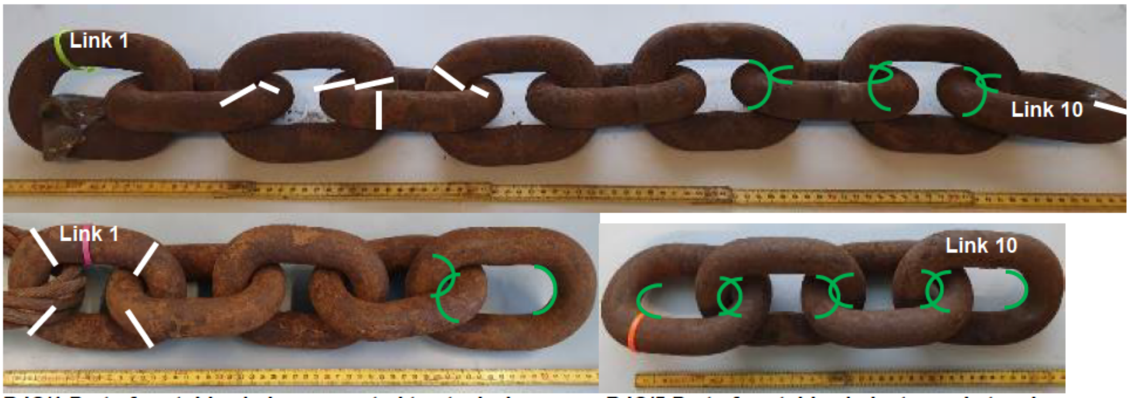
Figure 4-29 BJC/5 – Link 9 after cleaning. Significant interlink wear/deformation, indicated by arrows. No crack-like indications.

Figure 4-30 BJC/5 – Link 10 after cleaning. Significant asymmetric wear/deformation marks in the interlink areas, indicated by arrows. No crack-like indications.

The orientation of sample BJC/3 and BJC/5 was not marked on the received chain lengths. Hence, the order and orientation of the different chain segments relative to each other was determined based on the observed wear pattern, together with the known positions, and is shown in Figure 4-31. Included in Figure 4-31 are also the most significant wear and cracks found by visual examination. A comparison of wear pattern of the corresponding links from portside and starboard chain is shown in Figure 4-32.

Based on the comparison, the fractured link is number six, counted from the steel wire rope. According to the images shown in Figure 4-9 this link is positioned at the derrick head, where the chain gets in contact with the pin, and towards the steel wire rope side.

**BJC/3 Starboard chain**




**BJC/1 Part of portside chain, connected to steel wire rope** **BJC/5 Part of portside chain, towards trawl**

**Figure 4-31 Comparison of position of chain segments between the portside and the starboard chain. The white lines indicate observed crack-like indications, while the green markings show wear.**


**Figure 4-32 Comparison of wear pattern on links in corresponding position, between starboard and portside chain.**

## 4.4 Dimensional measurements

For all the received chain links, measurements of the chain link diameter in the two crowns and on the straight leg without weld was measured, as well as the inside and outside length. The two crown diameters are denoted 1 towards the steel wire rope side and 2 towards the trawl side. The results are given in Table 4-3 and the inner length and the minimum crown diameter are plotted in Figure 4-33 and Figure 4-34, respectively. For crown diameter, the first diameter is measured in the length direction of the chain, the second diameter is measured perpendicular to the length direction, i.e. the first measurement will show the interlink wear.

DNV

**Table 4-3 Dimension measurements for the different chain links.**

| Part ID | Description | Link no. | Inside length [mm] | Outside length [mm] | Diameter, crown 1 [mm] | Diameter crown 2 [mm] | Diameter, non-weld side [mm] |
|---|---|---|---|---|---|---|---|
| Part BJC/1 | Part of portside chain, connected to steel wire rope | 1 | 95.0 | 158.3 | 31.9 / 33.1 | 31.6 / 33.0 | 32.9 |
| | | 2 | 96.1 | 158.5 | 31.4 / 32.9 | 31.5 / 32.9 | 32.8 |
| | | 3 | 95.7 | 158.4 | 31.4 / 32.7 | 31.6 / 32.8 | 32.9 |
| | | 4 | 95.2 | 158.4 | 31.8 / 32.9 | 31.3 / 33.0 | 32.9 |
| | | 5 | 96.9 | 158.4 | 31.0 / 33.1* | 30.7 / 33.0* | 32.8 |
| Part BJC/2 | Unused section of chain** | 1 | 95.2 | 158.5 | 31.8 / 33.1* | 32.1 / 33.0* | 33.0 |
| | | 2 | 95.4 | 158.3 | 31.8 / 33.2 | 31.6 / 33.3 | 33.1 |
| | | 3 | 94.7 | 158.3 | 31.9 / 33.3 | 32.1 / 33.3 | 33.1 |
| | | 4 | 96.1 | 159.0 | 31.3 / 33.3 | 31.7 / 33.3 | 33.0 |
| | | 5 | 95.1 | 158.2 | 32.2 / 33.3 | 31.6 / 33.2 | 33.0 |
| | | 6 | 95.5 | 158.5 | 32.0 / 33.1 | 31.8 / 32.1 | 33.0 |
| | | 7 | 94.7 | 158.9 | 32.3 / 33.3 | 32.6 / 33.3 | 33.1 |
| | | 8 | 96.5 | 159.3 | 31.6 / 33.0 | 31.9 / 33.0 | 32.8 |
| | | 9 | 95.9 | 158.9 | 31.6 / 33.1* | 31.7 / 33.2* | 33.0 |
| Part BJC/3 | Starboard chain | 1 | 95.1 | 158.9 | 31.6 / 33.1* | 31.4 / 33.2* | 32.9 |
| | | 2 | 95.0 | 158.5 | 32.2 / 32.9 | 31.7 / 32.8 | 32.8 |
| | | 3 | 95.8 | 158.5 | 31.4 / 33.1 | 31.6 / 33.0 | 33.0 |
| | | 4 | 96.2 | 158.3 | 31.6 / 33.1 | 31.4 / 33.0 | 32.9 |
| | | 5 | 95.6 | 158.0 | 31.2 / 33.0 | 31.2 / 33.0 | 32.8 |
| | | 6 | 95.8 | 158.8 | 31.3 / 33.0 | 31.1 / 33.1 | 32.8 |
| | | 7 | 96.3 | 158.3 | 30.8 / 33.0 | 30.9 / 33.1 | 32.7 |
| | | 8 | 98.7 | 158.6 | 30.9 / 33.0 | 29.9 / 33.0 | 32.6 |
| | | 9 | 103.8 | 158.4 | 28.4 / 33.6 | 27.0 / 33.2 | 32.5 |
| | | 10 | 99.6 | 158.2 | 26.2 / 33.1* | 30.5 / 33.0* | 32.9 |
| Part BJC/4 | Part of fractured link, portside chain | 6 | - | - | 31.6 / 33.2 | - | - |
| Part BJC/5 | Part of portside chain, towards trawl | 7 | 96.6 | 158.2 | 31.3 / 33.0* | 31.4 / 33.0* | 32.8 |
| | | 8 | 99.4 | 158.5 | 31.0 / 32.9 | 28.2 / 33.3 | 32.8 |
| | | 9 | 101.8 | 158.0 | 27.4 / 33.2 | 28.7 / 32.9 | 33.0 |
| | | 10 | 96.7 | 158.8 | 30.2 / 32.9* | 27.9 / 33.1* | 32.9 |
| **Certificate** | | | | | | | |
| **Results** | | | - | | - | - | 32.7 |
| **Requirements** | | | - | | | | 32 ± 1.6 |
| Standards | | | | | | | |
| **NS-EN ISO 818-2 /1/** | | | - | | | | 32 ± 1.6 |
| **ASTM A391M /2/** | | | Max. 102.4 | | - | - | Min. 31.04 |

* Link can rotate around neighbouring link, hence crown 1 and crown 2 is chosen arbitrarily.

** Numbering or chain links chosen arbitrarily.

- No significant variations in outside length between the different chain links, neither between used and unused or along the length of the chain samples. This indicates that there is no significant elongation.

- No large differences in diameter on non-weld side between used and unused chain, i.e., only small loss in thickness due to corrosion. All measurements are within requirements according to NS-EN ISO 818-2 and ASTM A391 /1-2/ and correspond to the certificate.
- The inside length of the different links shows increased lengths towards the trawl side of the chain (higher link number), as shown in Figure 4-33. This is mainly caused by wear/deformation in the interlink area, as no increase in outer chain length is seen. The similar trend seen for both chains, indicate that the assumed orientation of the parts is correct.
- The minor crown diameter (the one along the length direction of the chain, i.e., the one decreased by interlink wear), is plotted versus link number in Figure 4-34. For both portside and starboard chain, there is a significant decrease due to wear/deformation in the links closer to the trawl (i.e., higher link numbers). This corresponds to the increasing measured inner length as the decrease in wear gives lower inner length. The cause of more wear is most likely more movement of chain links relative to each other in this area.
- Based on the plots, there is not expected significant interlink wear/deformation on the fractured chain link.

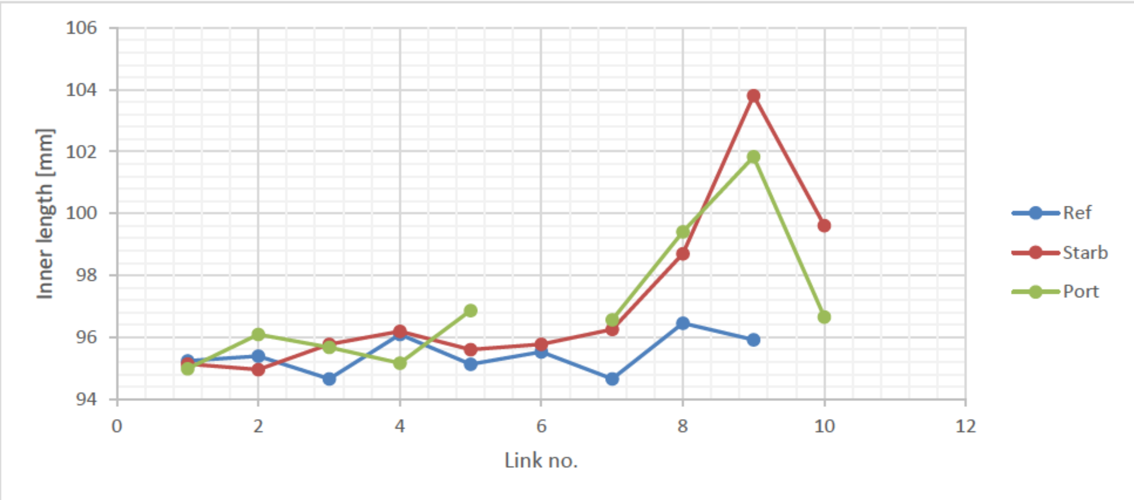



**Figure 4-33 Measured inner length plotted versus link number.**

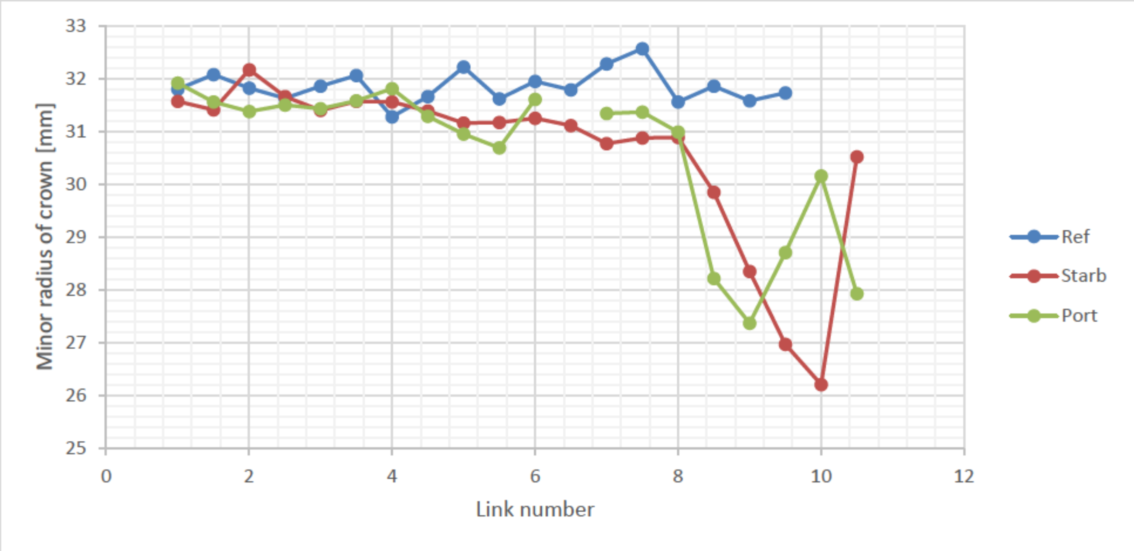



**Figure 4-34 Minor diameter of crown plotted versus link number.**

## 4.5 Visual examination of derrick heads

The derrick heads were sandblasted before the NDT, to remove paint and corrosion products, and most of the visual examination was performed after sandblasting. Significant wear is seen on both derrick heads, as shown in Figure 4-35. Close-up images of the wear/deformation on the pin and on the cheek plates are shown in Figure 4-36 and Figure 4-37. For both derrick heads, the wear/deformation is found on one side of the pin, i.e., upwards where the chain has been hanging over the pin. As shown in Figure 4-38, the geometry of the wear marks corresponds to the link geometry. The pink markings on several of the images shows the position of indications from MPI. These are believed to be folding of the material as the chain moves over the derrick head, i.e., related to the deformation of the surface material, and not cracks. See Paragraph 4.6 for MPI results.

Image courtesy of [Det Norske Veritas]


**Figure 4-35 Overview images of the two derrick heads.**

**Figure 4-36 Portside derrick head. Wear on both pin (left image) and cheek plates (right image).**

Image courtesy of [Det Norske Veritas]


**Figure 4-37 Starboard derrick head. Wear on both pin (left image) and cheek plates (right image).**


**Figure 4-38 Starboard derrick head. Comparison between wear marks and chain.**

## 4.6 Non-destructive testing

All the received chain links and the two derrick heads were examined using wet fluorescent MPI. Prior to testing, the used chain samples were cleaned overnight, using Valhall CleanCons, an industrial cleaner based on citric acid, phosphoric acid and inhibitors.

The test reports are included in Appendix C. The findings are summarised in Table 4-4.

**Table 4-4 Observations from MPI.**

| Part ID | Description | Link no. | |
|---|---|---|---|
| Part BJC/1 | Part of portside chain, connected to steel wire rope | 1 | Five linear indications |
| | | 2-5 | No indications |
| Part BJC/2 | Unused section of chain* | 1-9 | No indications |
| Part BJC/3 | Starboard chain | 1 | No indications |
| | | 2 | Three linear indications |
| | | 3 | Two linear indications |
| | | 4 | Five linear indications |
| | | 5 | One linear indication |
| | | 6 | One linear indication |
| | | 7 | One linear indication |
| | | 8-9 | No indications |
| | | 10 | Two linear indications |
| Part BJC/4 | Part of fractured link, portside chain | 6 | No indications |
| Part BJC/5 | Part of portside chain, towards trawl | 7 | No indications |
| | | 8** | One small indication |
| | | 9-10 | No indications |
| MPH/CM/PORT/3 | Portside derrick head | - | Three areas of indications |
| MPH/CM/SB/1 | Starboard derrick head | - | No indications |

* The thickness of the coating was measured to ca. 50 µm, hence the results are considered reliable, even for coated chain.

** The report states link no. 2 from the end marked with orange strip. This corresponds to link number 8.

The linear indications reported for the various chain links are crack like, and many of the indications correspond to the crack-like observations by visual examination.

The indications reported for the portside derrick head is most likely folding of the material, related to deformation of the derrick head pin, and not cracks.

## 4.7 Material characterisation of chain material

Samples for material characterisation were cut from the following links:

- Part BJC/1 – Link 5 (Short name: 1-5)
- Part BJC/2 – Link 9 (Short name: 2-9)
- Part BJC/3 Link 1 (Short name: 3-1)
- Part BJC/5 – Link 10 (Short name: 5-10)
- Part BJC/4 (Fractured link)

Cutting was performed as show in Figure 4-10.

Material characterisation includes metallographic examination, hardness testing, estimation of tensile strength and chemical analyses.

### 4.7.1 Metallographic examination

Cross sections were cut from four links, in addition to the fractured link. The cut surface was prepared by standard metallographic methods and etched using 2% Nital (nitric acid in ethanol) to reveal the microstructure.

All the examined cross sections had a quenched and tempered microstructure, as expected. This is also as specified both in NS-EN ISO 818-2 and ASTM A391 /1-2/. No significant differences are observed between the different links or between different areas of each cross section.

A typical example of the microstructure is shown in Figure 4-39. Total documentation is given in Appendix B.

The cross sections also show examples of corrosion pits on the chain surface, see Figure 4-40.

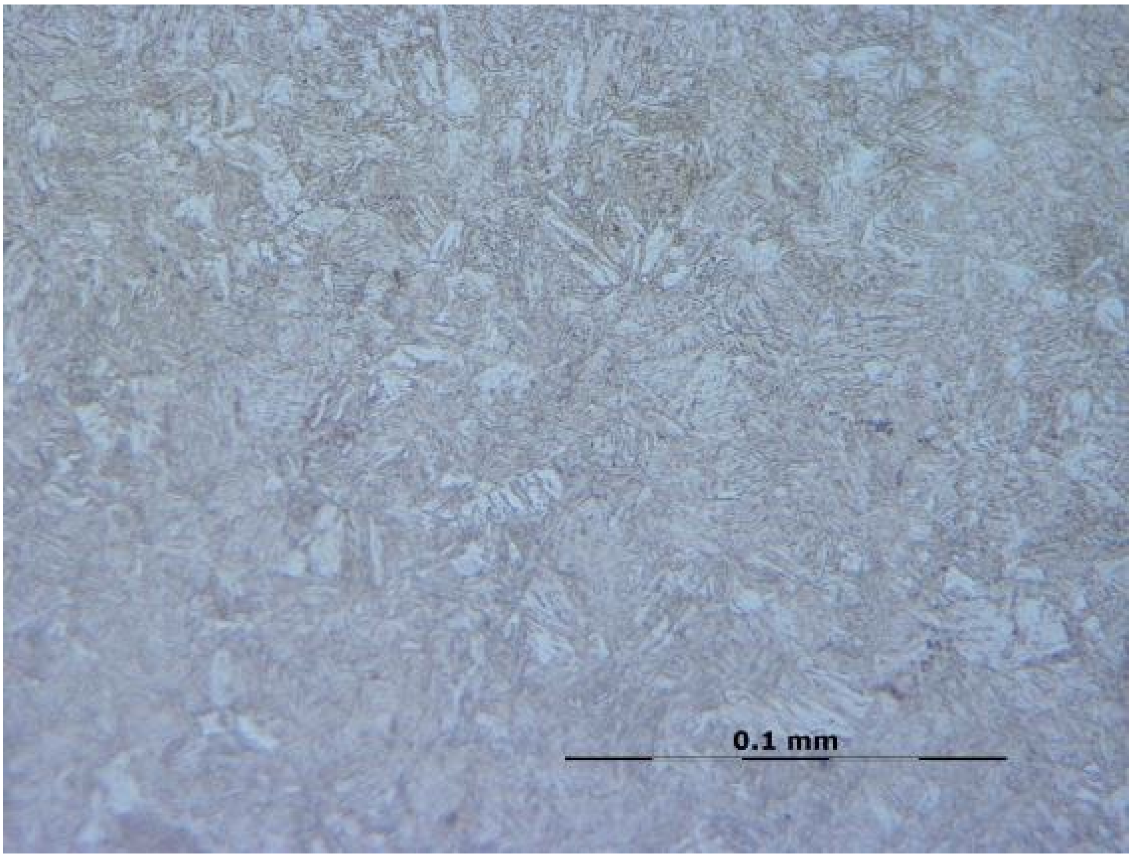



**Figure 4-39 Typical example of quenched and tempered microstructure of chain material, fractured link: Quenched and tempered microstructure ca 10 mm from outer surface.**

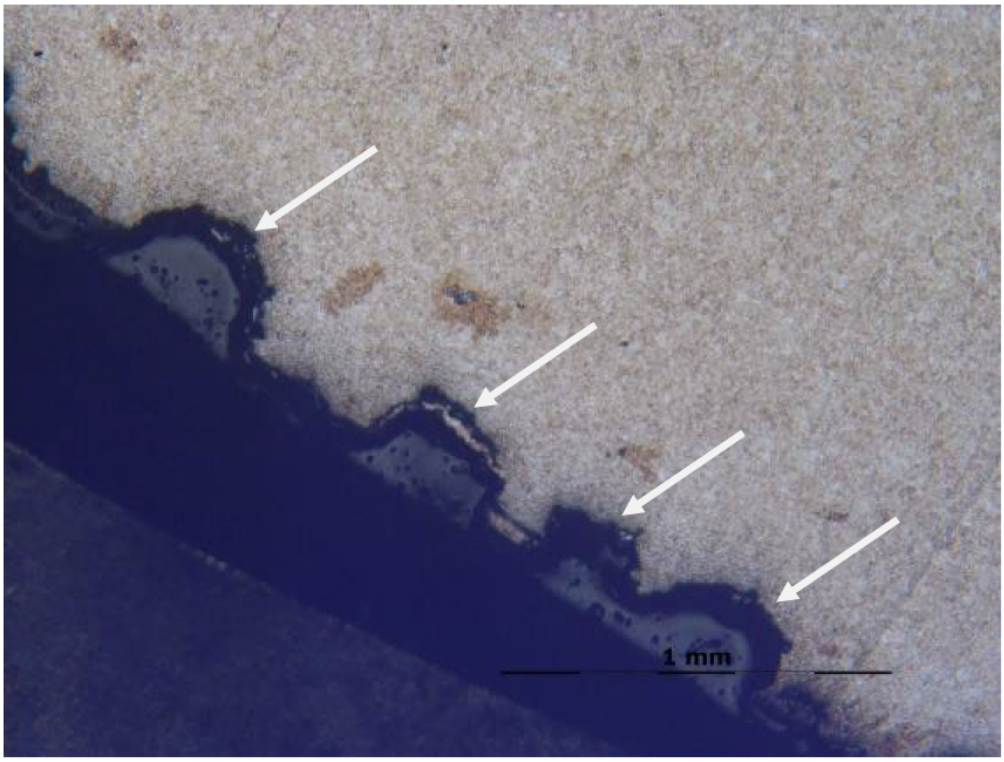



**Figure 4-40 Typical examples of corrosion pits on the link surfaces, sample 1-5. Four major pits are indicated by arrows.**

## 4.7.2 Hardness testing and estimation of tensile strength

On the same cross sections as was used for metallographic examination, hardness surveys were performed.

Hardness was measured using Vickers hardness method and 10 kg load, according to NS-EN ISO 6507-1 /3/. The average hardness results were converted to estimated tensile strength and Brinell hardness according to NS-EN ISO 18265, Table B.2 /4/. Results from hardness testing of the cross sections are shown in Table 4-5, and a drawing showing the position of the different measurements is shown in Figure 4-41.

Hardness measurements were also performed on a cross section through the fracture initiation area of fracture A, see Figure 4-4 for naming of fracture surfaces. The results are given in Table 4-6 and a drawing showing the position of the different measurements is given in Figure 4-42.

Average hardness values obtained varies in the range of 419 to 438 HV10, where the lower values are measured close to the surface, and the higher values are measured in the core/main part of the cross section. The results from hardness measurements show only small differences in hardness between the different chain links.

The measured hardness and estimated tensile strength in the fracture initiation area is somewhat lower compared to the values from the surface area of the cross sections on the other chain links. The hardness measured on the cross sections correspond well with the hardness of the other chain links (portside, starboard and reference chain).

Neither NS-EN ISO 818-2 or ASTM A391 /1,2/ gives any requirements to hardness or tensile strength of the material. NS-EN ISO 818-2 /1/ states that the break load is calculated based on a tensile strength of 800 N/mm$^2$. However, these calculations do not take into account the real geometry of the chain, hence a significantly higher tensile strength is needed to obtain the required break load.

According to a test certificate from the manufacturer, forwarded by the client (given in Appendix F), the expected hardness is 375 HB, corresponding to 380 HV10, according to NS-EN ISO 18265 /4/. Brinell hardness cannot be compared directly to Vickers hardness, however an estimated converted value for Vickers hardness is found, using NS-EN ISO 18265 /4/. The obtained results are significantly above this value.

**Table 4-5 Results from hardness testing.**

| Sample | Measured hardness {HV10} | | | | |
|---|---|---|---|---|---|
| | Link 1-5 | Link 2-9 | Link 3-1 | Link 5-10 | Fractured |
| | Portside chain | Unused reference | Starboard chain | Portside chain | Portside chain |
| Surface 1 | 415<br>421<br>426 | 419<br>418<br>422 | 424<br>422<br>425 | 424<br>428<br>438 | 417<br>425<br>422 |
| ½ radius 1 | 435-437-438 | 443-443-431 | 410-419-413 | 444-445-448 | 436-434-434 |
| Mid | 522-438-419 | 423-420-394 | 448-420-459 | 420-401-416 | 420-417-417 |
| ½ radius 2 | 424-415-411 | 443-448-449 | 451-452-449 | 443-444-447 | 429-437-433 |
| Surface 2 | 420<br>420<br>417 | 434<br>432<br>429 | 431<br>426<br>420 | 409<br>409<br>420 | 421<br>428<br>421 |
| **Average values** | | | | | |
| Average, surface | 420 | 426 | 425 | 421 | 422 |
| Average, core | 438 | 433 | 436 | 434 | 429 |
| Total average | 431 | 430 | 431 | 429 | 426 |
| **Values converted from total average, according to NS-EN ISO 18265, Table B.2 /4/** | | | | | |
| Tensile strength [N/mm$^2$] | 1344 | 1341 | 1344 | 1338 | 1329 |
| Brinell hardness [HB] | 425 | 424 | 425 | 423 | 420 |

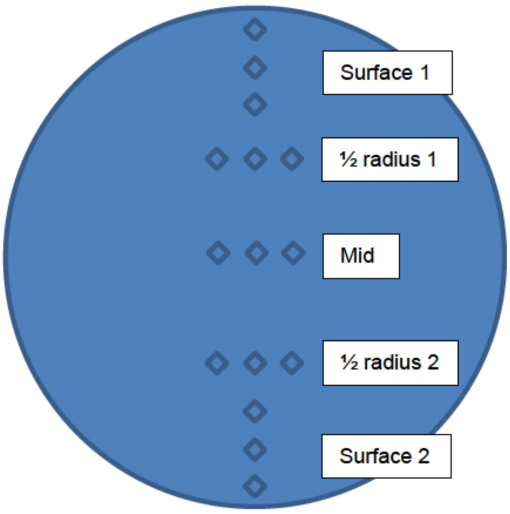



**Figure 4-41 Drawing showing the schematic position of the hardness measurements. Note that the drawing is not to scale. The distance between the measurements in each group is 1 mm.**

**Table 4-6 Results from hardness testing of cross section through fracture initiation.**

| Sample | Close to fracture surface |
|---|---|
| Along fracture surface | 428-416-416-408-415 |
| Along link surface | 418<br>423<br>427<br>423 |
| Total average | 419 |
| Values converted according to NS-EN ISO 18265, Table B.2 /4/ | |
| Tensile strength [N/mm²] | 1308 |
| Brinell hardness [HB] | 413 |

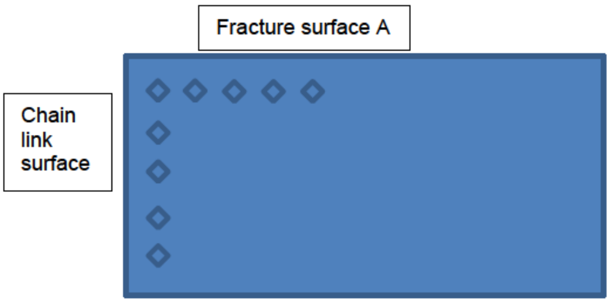



**Figure 4-42 Position of the hardness measurements on the cross section through the fracture initiation area (fracture surface A). The indents are positioned 1 mm from the chain link surface/fracture surface and 1 mm from each other.**

## 4.7.3 Chemical analyses

Spectrometric analyses were performed by Degerfors Laboratorium AB on material from five links. The results are given in Table 4-7 together with relevant requirements. The chemical composition given in the chain certificate is included for comparison. The report from Degerfors Laboratorium AB is enclosed in Appendix D.

**Table 4-7 Results from chemical analyses.**

| Sample | Chemical composition [wt%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Cr | Ni | Mo | Cu | Al |
| 1-5 | 0.23 | 0.23 | 1.25 | 0.015 | 0.005 | 0.58 | 0.50 | 0.25 | 0.14 | 0.026 |
| 2-9 | 023 | 0.23 | 1.26 | 0.015 | 0.005 | 0.58 | 0.49 | 0.25 | 0.14 | 0.025 |
| 3-1 | 0.23 | 0.23 | 1.26 | 0.015 | 0.005 | 0.58 | 0.49 | 0.25 | 0.14 | 0.025 |
| 5-10 | 0.24 | 0.23 | 1.25 | 0.015 | 0.005 | 0.58 | 0.49 | 0.25 | 0.14 | 0.026 |
| Fractured link | 0.23 | 0.23 | 1.25 | 0.015 | 0.004 | 0.58 | 0.49 | 0.25 | 0.14 | 0.024 |
| **Certificate** | | | | | | | | | | |
| | 0.211 | 0.216 | 0.215 | 0.0154 | 0.0064 | 0.567 | 0.510 | - | - | 0.0281 |
| **Requirements according to relevant standards** | | | | | | | | | | |
| NE-EN 818-2 /1/ | | | | 0.025 (cast) / 0.030 (Check) | 0.025 (cast) / 0.030 (Check) | Min. 0.40* | Min. 0.40 | Min. 0.15* | | Min. 0.025 |
| ASTM A391 /2/ | Max. 0.35 | | | Max. 0.025 | Max. 0.025 | Min. 0.40* | Min. 0.40 | Min. 0.15* | | |

* Required amount of either chromium or molybdenum.

The analysed chemical composition of the different samples shows good correspondence, with variation within or close to the uncertainty of measurement stated in the test reports. The only result that does not meet the requirements according to NS-EN ISO 818-2 and ASTM A391 /1-2/ is the aluminium content of the sample from the fractured link. However, the deviation is within the uncertainty of measurement stated in the test report.

The results correspond well to the results stated in the certificate, unless for manganese, where the analysed quantity is nearly six times higher compared to the value stated in the certificate. The relevant standards do not give any requirement for manganese content.

## 4.8 Break load testing

### 4.8.1 Test samples

Two chain segments were tested:

- Part BJC/3, starboard used chain, chain links 3 to 9
- Part BJC/2, unused reference chain

The links were marked by letters for internal ID during testing.

### 4.8.2 Test machine

The testing was performed at DNV GL's "Technology Centre for Offshore Mooring and Lifting" in Bergen, Norway, utilizing the 28.5 MN capacity tensile testing machine. The tensile testing machine operates by the principle of one fixed cross-head (the "static end") and one moving cross-head (the "active end"). The static end is connected to a hydraulic cylinder that can shift the test set-up with increments of 800 mm without unloading the test object (during testing the static end is fixated by pins). This is necessary if the test specimen elongates more than the total stroke length of the main cylinder. Illustration of the test bed is presented in Figure 4-43.

The Certificate of Calibration is enclosed in Appendix E.

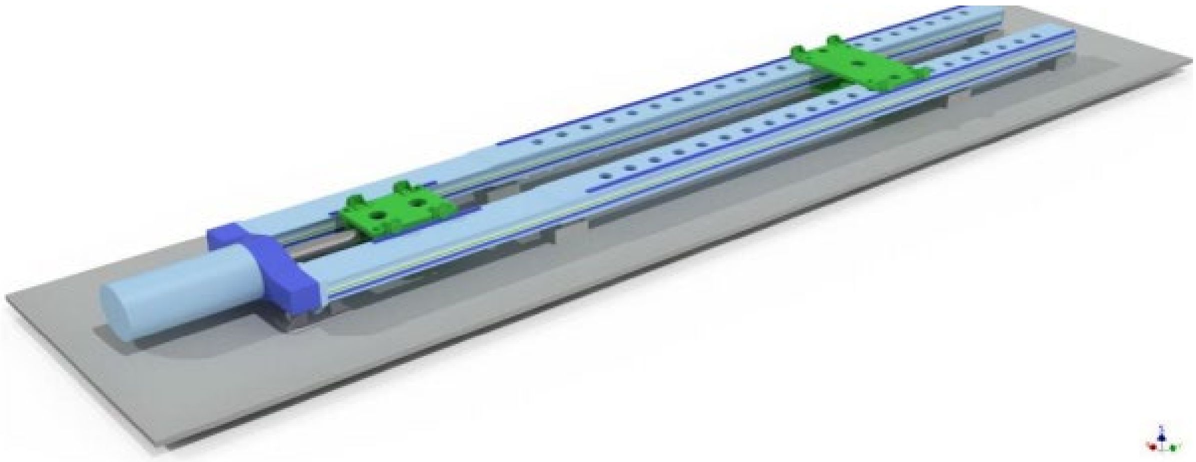


**Figure 4-43 Illustration of 28.5 MN capacity tensile tester's test bed.**

## 4.8.3 Test procedure

The chain segments were loaded at a loading rate of 15 mm/minute from the start. As the chain segment started yielding, the loading rate was gradually increased to maintain a constant load per time rate (kN/min).

## 4.8.4 Test results

The obtained breaking loads and location of failure is presented in Table 4-8. For both chain segments, the obtained break load is below the requirement for a Ø32 mm Grad 8 chain according to NS-EN ISO 818-2 and ASTM A391 /1-2/.

**Table 4-8 Obtained breaking loads and location of fracture.**

| Test id.: | Obtained breaking load | Location of fracture |
|---|---|---|
| Part BJC/3, starboard used chain (including several links with crack-like indications) | 223 kN | Three fractures of link 4 |
| Part BJC/2, unused reference link | 994 kN | Crown of middle link |
| **Requirements according to relevant standards** | | |
| NS-EN ISO 818-2 /1/ | 1290 kN | - |
| ASTM A391 /2/ | 1288 kN | - |
| **Certificate** | | |
| **Result** | 1480 kN | - |
| **Requirement** | 1290 kN | - |

Tension vs. total elongation graphs are presented in Figure 4-44 to Figure 4-46.

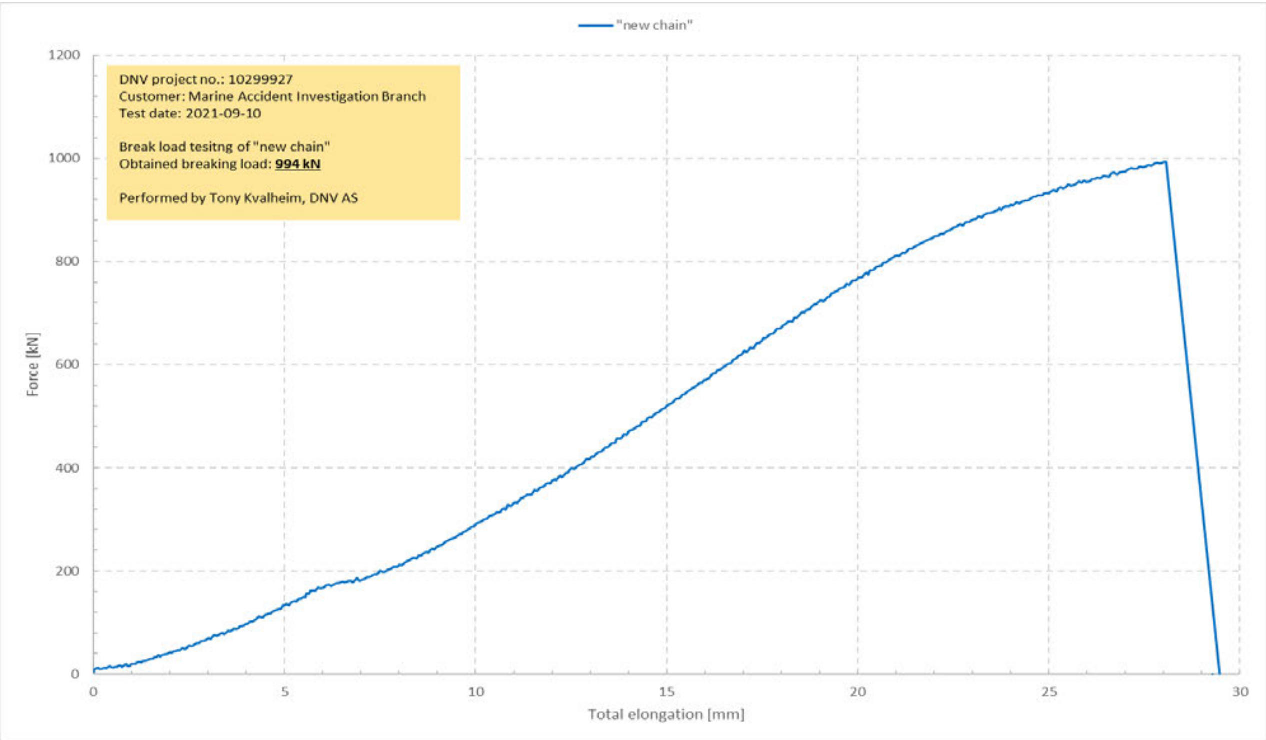



**Figure 4-44 Part BJC/2, unused reference chain, tension versus total elongation.**

Image courtesy of [Det Norske Veritas]

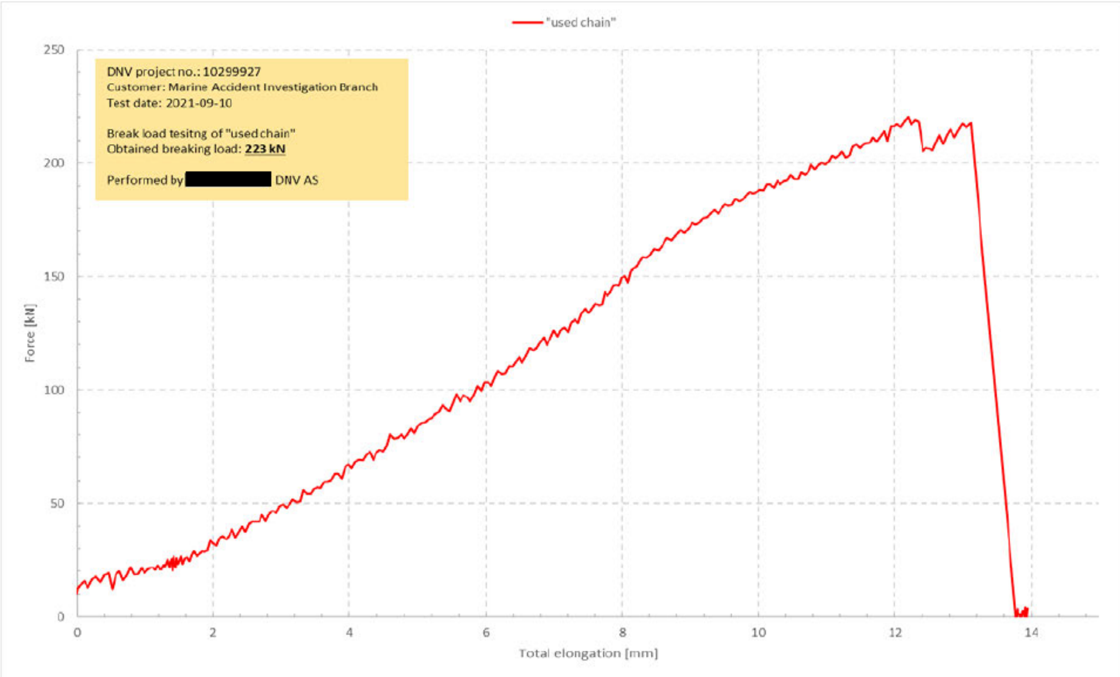



**Figure 4-45 Part BJC/3, starboard used chain, tension versus total elongation.**

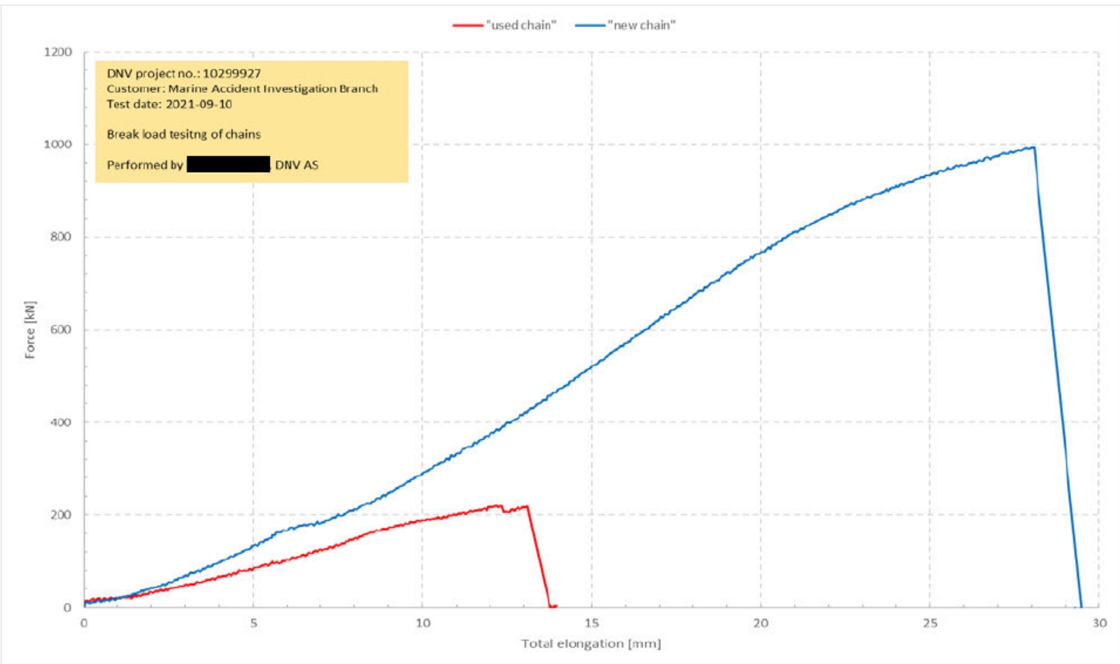



**Figure 4-46 Part BJC/2, unused reference chain (blue) and Part BJC/3, starboard used chain (red), tension versus total elongation.**

### 4.8.5 Visual examination of break load test sample, unused reference sample

Images showing the break load test sample from the unused reference sample, Part BJC/2, are given in Figure 4-47.

The fracture has initiated from the inside of the crown of one of the mid chain links, and has a typical appearance for an overload fracture. No indication of pre-existing crack (i.e. areas of corrosion on the fracture surface) is seen.

**Figure 4-47 Break load testing of unused reference sample. The upper image shows the whole length after break load testing, the lower images show the fractured link. The letters on the chain links are for internal use only.**

### 4.8.6 Visual examination of break load test sample, used starboard chain

Images showing the break load test sample from the used starboard chain, Part BJC/3, links 3 to 9 are given in Figure 4-48. The fractured link is link 4, see Figure 4-20.

The fractured link has a total of four cracks, three that have opened during testing, and one that is still closed. The fracture surface of the three opened cracks are shown in Figure 4-49. For all the three cracks that has opened during testing, an area of corrosion is seen, showing the cracks prior to testing. One of the fractures has grown all through the thickness of the link in service, meaning that the chain link has worked more or less like a C-hook during the last time in service. No significant plastic deformation is seen for the fractured link. The fractures correspond to the crack-like indications seen prior to testing, see Figure 4-20.

**Figure 4-48 Break load testing of starboard chain. The upper image shows the whole length after break load testing, the lower images show the fractured link. The letters on the chain links are for internal use only. The strips used for marking are shifted to the end links after cutting, to ensure that the orientation is kept. The yellow strip on link 3 (link to the right) was loosened during testing, however, is included in the images.**

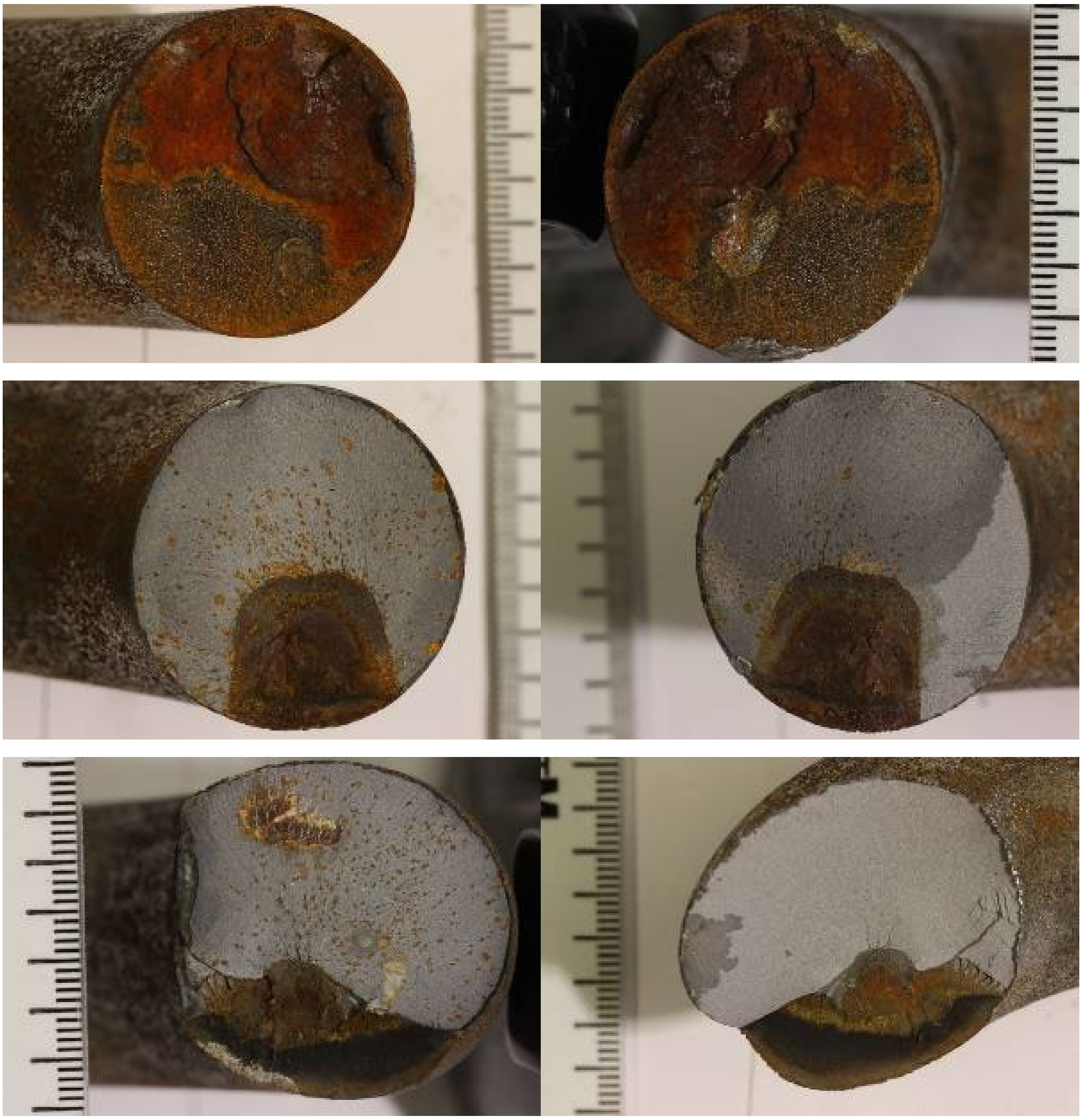


**Figure 4-49 Break load testing of starboard chain. All three fracture surfaces have areas of cracks present in the chain prior to testing, seen as rust-coloured area.**

## 4.9 Tensile testing of chain material

Tensile test specimens (Ø 10 mm) were sectioned in the longitudinal direction of the leg opposite to the weld, from the link two links away from the fractured link (BJC/1 – Link 4) and from one link from the reference chain (BJC/2). Due to limited material, the sample from the reference link was shorter than a proportional sample, however had the same diameter as the sample from the chain with the fractured link. Additional elongation at a shorter gauge length (32 mm (denoted A) instead of 50 mm (denoted $A_5$)) was also calculated for comparison.

Testing was performed at room temperature and in accordance with NS-EN ISO 6892-1 /5/. The results from tensile testing are shown in Table 4-9. Stress-strain plots for the two tests are shown in Figure 4-50. Neither NS-EN ISO 818-2 /1/ nor ASTM A391 /2/ gives relevant requirements, hence, requirements for Grade R6 mooring chain according to DNV-OS-E302 /9/ are included for comparison. Grade R6 is the type of mooring chain with higher strength requirements.

**Table 4-9 Results from tensile testing.**

| Sample | Sample diameter [mm] | Original gauge length, $L_0$ [mm] | Yield strength, $R_{p0.2}$ [MPa]* | Tensile strength, $R_m$ [MPa] | Elongation $L_0$ = 50 mm [%] | | Elongation $L_0$ = 32 mm [%] | | Contraction | | Fracture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $L_U$ [mm] | $A_5$ [%] | $L_U$ [mm] | A [%] | $d_u$ [mm] | Z [%] | |
| BJC/1 – link 4 Portside chain | 9.92 | 50 | 1328* | 1341 | 55.67 | 11.5 | 37.36 | 17 | 6.30 | 59 | Cup and cone |
| BJC/2 Unused, ref. chain | 9.94 | 32 | 1403* | 1406 | NA | NA | 36.26 | 13.5 | 6.69 | 56 | Cup and cone |
| **Minimum requirement for mooring chain according to DNV-OS-E302 /9/** | | | | | | | | | | | |
| Grade R6 | - | - | Min. 900 | Min. 1100 | - | Min. 12 | - | - | - | 50 | - |

* Yield strength is determined manually from stress/strain plot as shown below.

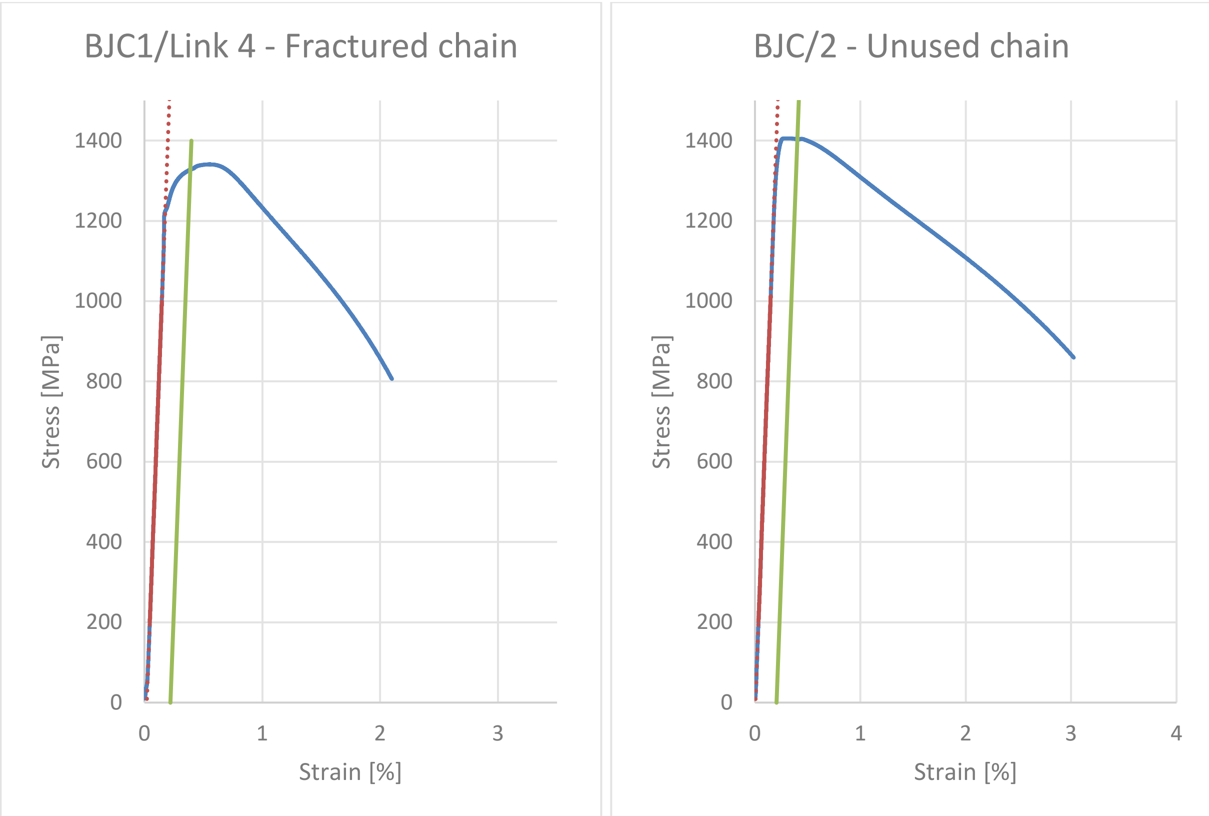



**Figure 4-50 Stress-strain plots from tensile testing. The red and green lines are used for determination of the 0.2% yield strength.**

The test results show small difference between the yield strength and the tensile strength for both samples. The test results show higher tensile strength and yield strength of the reference chain, and correspondingly lower elongation (based on $L_0$ = 32 mm) and contraction.

The tensile strength values estimated based on hardness measurements are in the range of 1329-1344 MPa, which correspond very well to the tensile strength of the sample from the fractured chain (BJC/1 – Link 4), while the tensile strength of the reference chain is higher.

As no requirements are given in the relevant standards, requirement for the most high-strength grade of mooring chain according to DNV-OS-E302 /9/ are included for comparison. The yield and tensile strength results for both samples are considerably higher than the minimum requirements for anchor chain of grade R6. The $A_5$ elongation of the sample from the fractured chain (BJC/1 – Link 4) is below the minimum requirement and based on the comparison of the elongation measured on a shorter length, it is assumed that the $A_5$ elongation of the sample from the reference chain would be significantly below the requirement.

## 4.10 Material testing of derrick head material

Two samples were sectioned from the derrick heads:

- MPH/CM/PORT/3 – Portside derrick head: Sample from the cheek plate material
- MPH/CM/SB/1 – Starboard derrick head: Sample from the pin material

### 4.10.1 Chemical analyses

Spectrometric analyses were performed by Degerfors Laboratorium AB on material from the derrick heads. The results are given in Table 4-7 together with relevant requirements. The report from Degerfors Laboratorium AB is enclosed in Appendix D.

**Table 4-10 Results from chemical analyses**

| Sample | Chemical composition [wt%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Cr | Ni | Mo | Cu | Al |
| Cheek plate material (MPH/CM/PORT/3) | 0.15 | 0.03 | 1.09 | 0.010 | 0.015 | 0.03 | 0.02 | <0.01 | 0.017 | 0.004 |
| Pin material MPH/CM/SB/1 | 0.42 | 0.33 | 0.81 | 0.020 | 0.041 | 1.07 | 0.02 | 0.19 | 0.054 | 0.019 |

The analyzed chemical composition of the two samples shows that both materials are carbon steel. The chemical composition of the cheek plate material (PORT/3) correspond to various structural steels. The chemical composition of the pin material could be a type of alloy steel.

### 4.10.2 Metallographic examination

Cross sections were cut from both samples. The cut surfaces were prepared by standard metallographic methods and etched using 2% Nital (nitric acid in ethanol) to reveal the microstructure. Images showing the microstructure of the two are given in Figure 4-51 and Figure 4-52

The examined cross sections from the pin material had a quenched and tempered microstructure, while the cross section from the cheek plate material had a ferritic-pearlitic microstructure.

Image courtesy of Det Norske Veritas

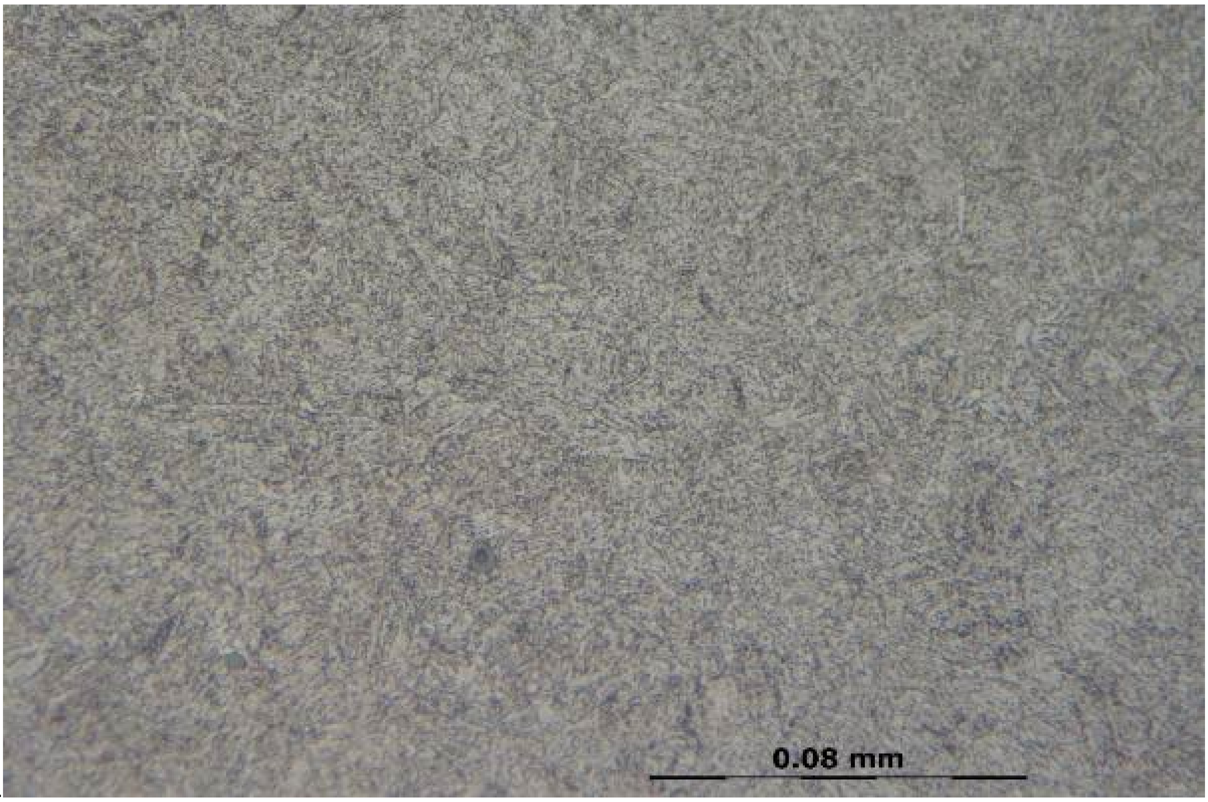



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**Figure 4-51 Cross section, pin material of derrick head (MPH/CM/SB/1). Quenched and tempered microstructure.**

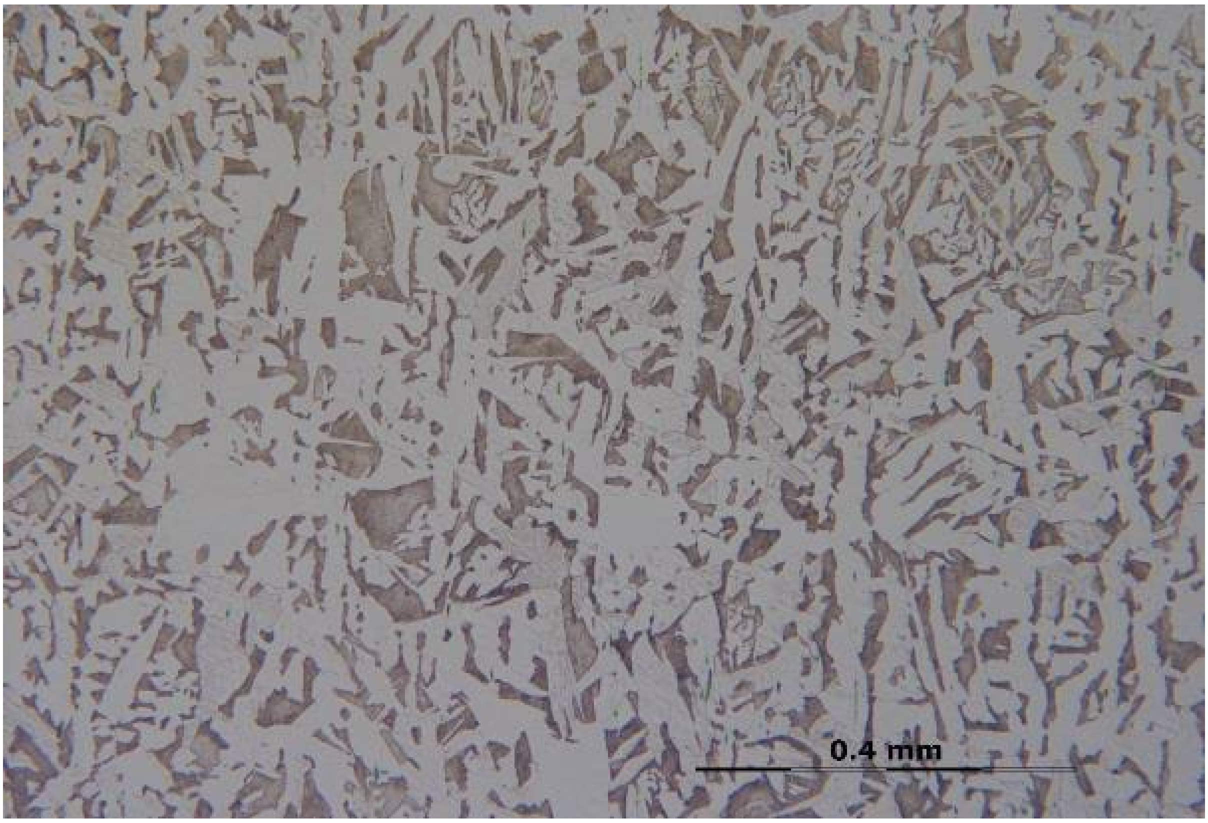



**Figure 4-52 Cross section, cheek plate material of derrick head (MPH/CM/PORT/3). Ferrite-pearlite microstructure.**

### 4.10.3 Hardness testing and estimation of tensile strength

On the same cross sections as was used for metallographic examination, hardness surveys were performed.

Hardness was measured using Vickers hardness method and 10 kg load, according to NS-EN ISO 6507-1 /3/. The average hardness results were converted to estimated tensile strength according to NS-EN ISO 18265, Table A.1 for the cheek plate material and Table B.2 for the pin material /4/. For the cheek plate material, the measurements were made approximately ¼ thickness from the surface, for the pin material, the measurements were made approximately 1 cm from the outer surface. Results from hardness testing of the cross sections are shown in Table 4-5.

**Table 4-11 Results from hardness testing.**

| **Sample** | **Measured hardness {HV10]** | |
|---|---|---|
| | **MPH/CM/PORT/3 – Portside derrick head** | **MPH/CM/SB/1 – Starboard derrick head** |
| | **Cheek plate material** | **Pin material** |
| Single values | 118-117-115 | 274-269-270 |
| Average, surface | 117 | 271 |
| **Values converted from total average, according to NS-EN ISO 18265 /4/** | | |
| **Table in NS-EN ISO 18265** | **A.1** | **B.2** |
| Tensile strength [$N/mm^2$] | 376 | 816 |

Both hardness results and estimated tensile strength values seem reasonable compared to the observed microstructure.

### 4.10.4 Summary of characterization of derrick head materials

The examination shows that the derrick heads consist of two different material types. Based on the use, it is reasonable that the pin is a higher strength material compared to the cheek plate.

The cheek plates are most likely a low-alloy construction steel, while the pin is a quenched and tempered alloy steel.

Image courtesy of Det Norske Veritas

# 5 EXAMINATION OF FRACTURED CHAIN LINK, PART BJC/4

## 5.1 Visual examination

An overview image showing the fractured chain link as received is shown in Figure 5-1. The fracture surfaces were protected using grease, and the link was wrapped in plastic film when received. The grease and loose corrosion particles were removed using cotton rags and ethanol, and overview images showing the fractured link prior to any chemical cleaning is shown in Figure 5-2 and Figure 5-3. The two fracture surfaces were denoted A and B as shown in Figure 5-1.

The visual examination shows significant corrosion and no remains of coating on the chain link surface. The chain link surface as received has less corrosion products and flaking compared to the surface of the other used chain that were examined. This could be related to more handling, etc. prior to being wrapped up to be forwarded to DNV.

The fractured piece has two fracture surfaces. One surface, denoted A, that is relatively flat and oriented more or less perpendicular to the length direction of the chain link. The second fracture surface, denoted B, has a rougher appearance.

There is only limited plastic deformation in the vicinity of the two fractures.

Corrosion is observed on both fracture surfaces.


**Figure 5-1 BJC/4 – Fractured link: As received. The fracture surfaces were protected using grease.**


**Figure 5-2 Overview images showing the fractured link after cleaning using cotton rags and ethanol.**


**Figure 5-3 Overview images of the two fracture surfaces, after cleaning using cotton rags and ethanol.**

## 5.2 Fractographic examination

The fractured link part was further cleaned using inhibited hydrochloric acid to remove corrosion products. The two fractures were cut from the link part as shown in Figure 5-4 for easier handling and examination using a scanning electron microscope.

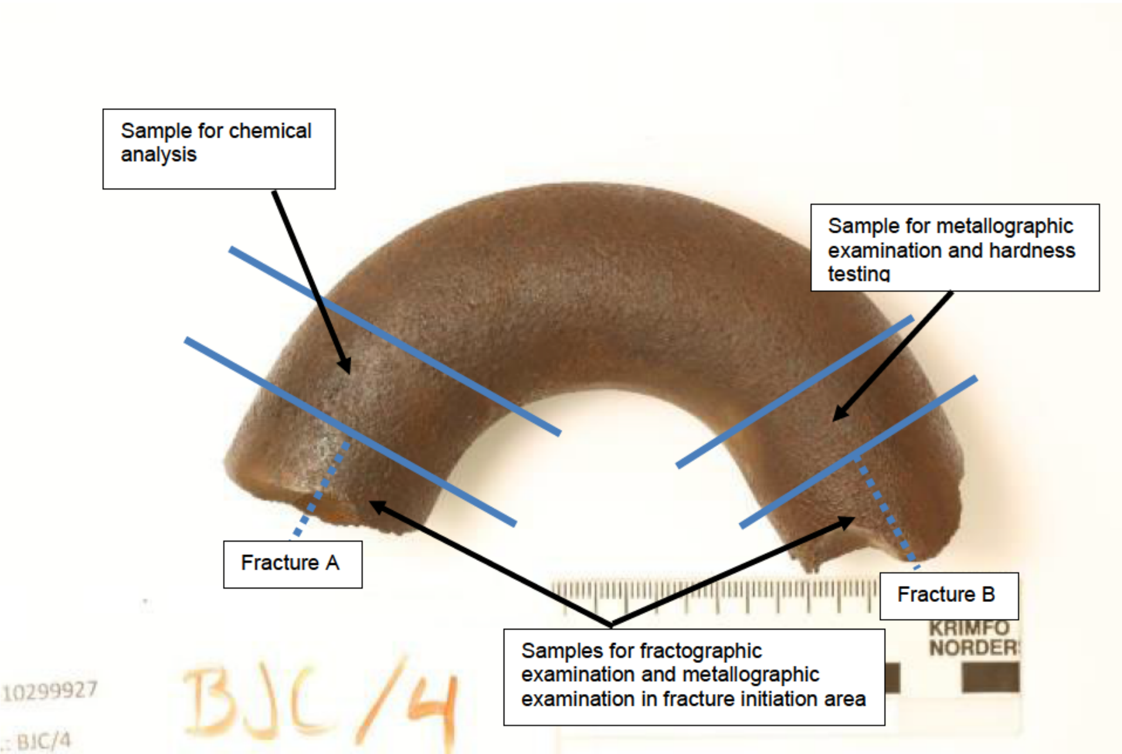



**Figure 5-4 Cutting of fractured chain link.**

### 5.2.1 Fracture A

An overview image showing fracture A after careful cleaning using inhibited hydrochloric acid, is shown in Figure 5-5.

The fracture surface has a likely fracture initiation area as is indicated in Figure 5-5. In this area ratchet marks / breakover lines are seen, and weak indication arc-shaped features radiating outwards from the initiation area. This indicates crack growth from multiple initiation points. Ratchet marks / Breakover lines form when two (or more) cracks from different initiation points meet and grows together into one crack. The initiation area is seen along the edge of the fracture surface, approximately 90° from the interior/exterior curve of the link (i.e. 90° from the intrados/extrados). An image showing the initiation area at higher magnification is given in Figure 5-6.

Examining the link surface close to the initiation area, a number of small cracks were found close to the fracture initiation area, as shown in Figure 5-7. These are believed to be similar cracks that have initiated in parallel with the main crack, however has not propagated further.

The main part of the fracture surface shows an inner relatively smooth area, surrounded by an area with rougher topography, more like a river pattern. This indicates a change in crack growth rate as the crack has propagated outwards.

The upper edge of the fracture surface, ca 180° from the initiation area, is plastically deformed, see Figure 5-5. This is a secondary damage, most likely formed in an impact when the fractured link fell down after the failure of the chain. In this area, there is possibly a small overload fracture, however this cannot be assessed, due to the secondary damage.

Figure 5-8 shows a crack branching from the main fracture.

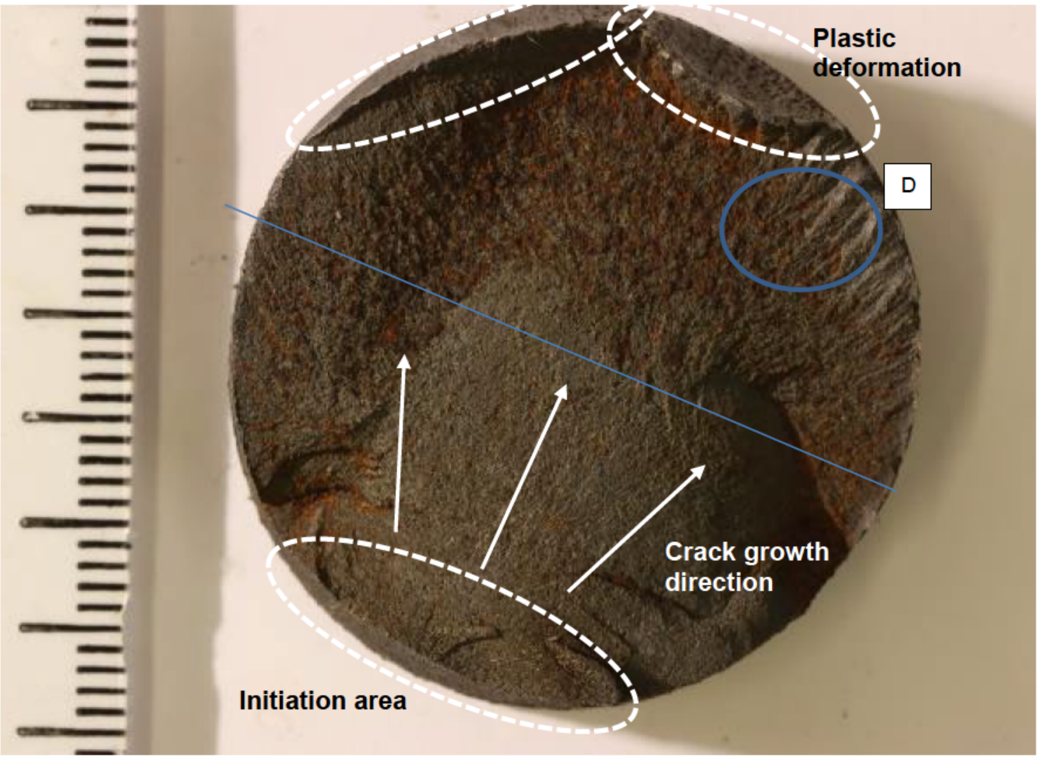



**Figure 5-5 Overview image showing fracture surface A after careful chemical cleaning. The marked Area D refers to the SEM image given in Figure 5-16. The approximate position of the line between the intrados and the extrados (inner and outer curve) is included as a blue line, as the curvature of the link cannot be seen. Fracture initiation area and crack growth direction (white arrows) are included in the lower part of the figure. The latter shown by the white arrows. Plastic deformation is shown in the upper part of the image.**

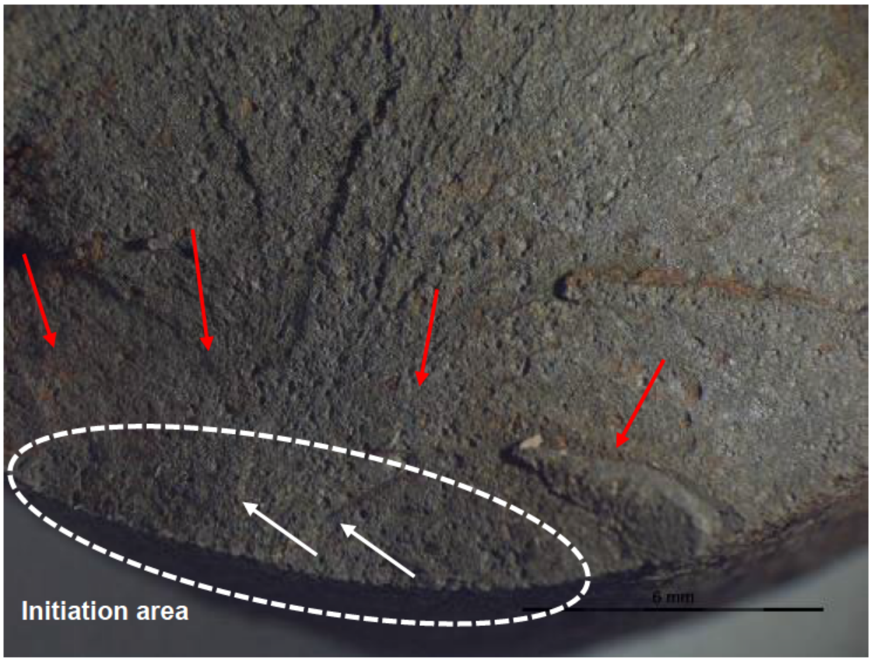



**Figure 5-6 Fracture A: Fracture initiation area. Break-over lines and indication of arc-shaped features radiating outwards from the initiation area is seen, and marked by white and red arrows, respectively.**

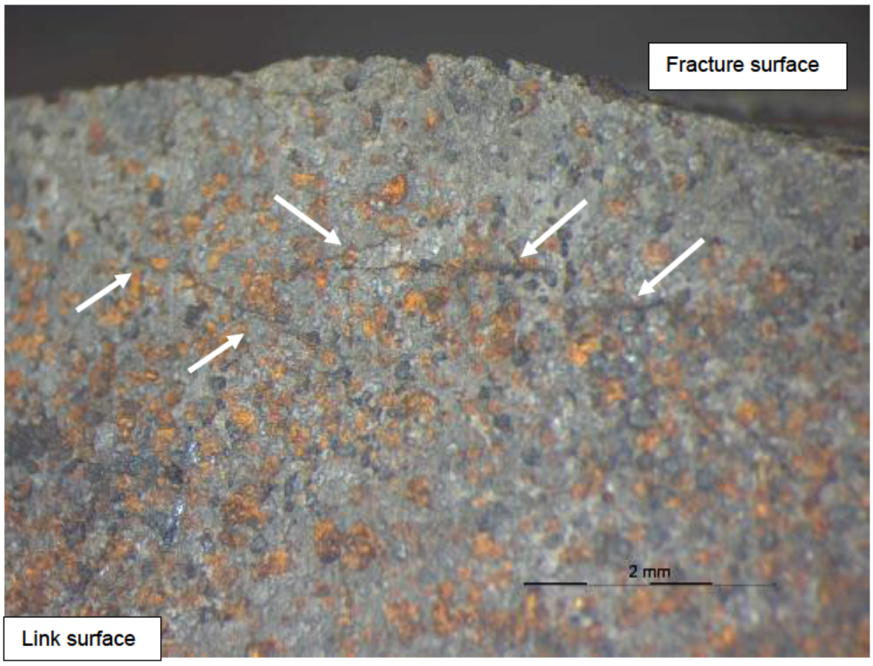



**Figure 5-7 Fracture A: Cracks on the link surface, more or less parallel to the main crack, close to the initiation area. Cracks shown by arrows.**

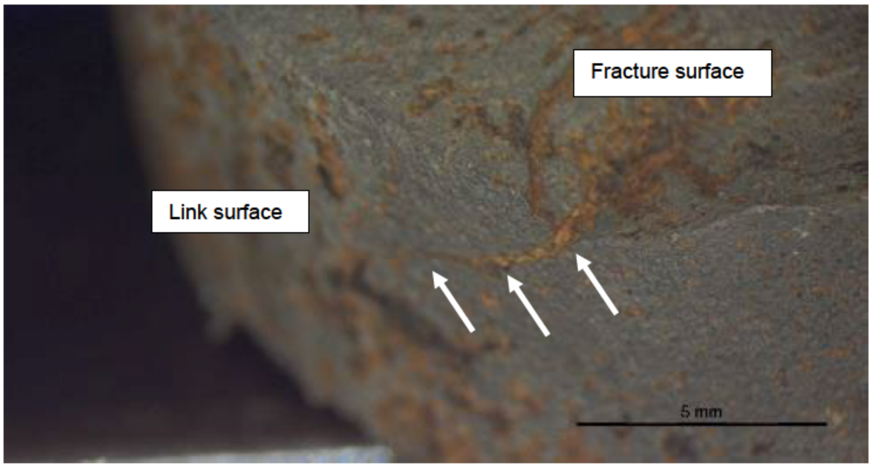



**Figure 5-8 Fracture A: Crack branching from the fracture surface, indicated by arrows**

### 5.2.2 Examination of fracture A, using scanning electron microscope

Both the chain link surface close to the initiation area and the fracture surface was examined at higher magnification using a scanning electron microscope. More cleaning using inhibited hydrochloric acid was performed to remove non-conductive corrosion products.

As shown in Figure 5-9, an area of multiple cracking is found on the chain link surface, close to the fracture initiation area. It is noted that most of the cracks are parallel to the fracture surface, however a crack nearly perpendicular to the fracture is also found. The cracks have a jagged appearance on the link surface, indicating to intergranular cracking.

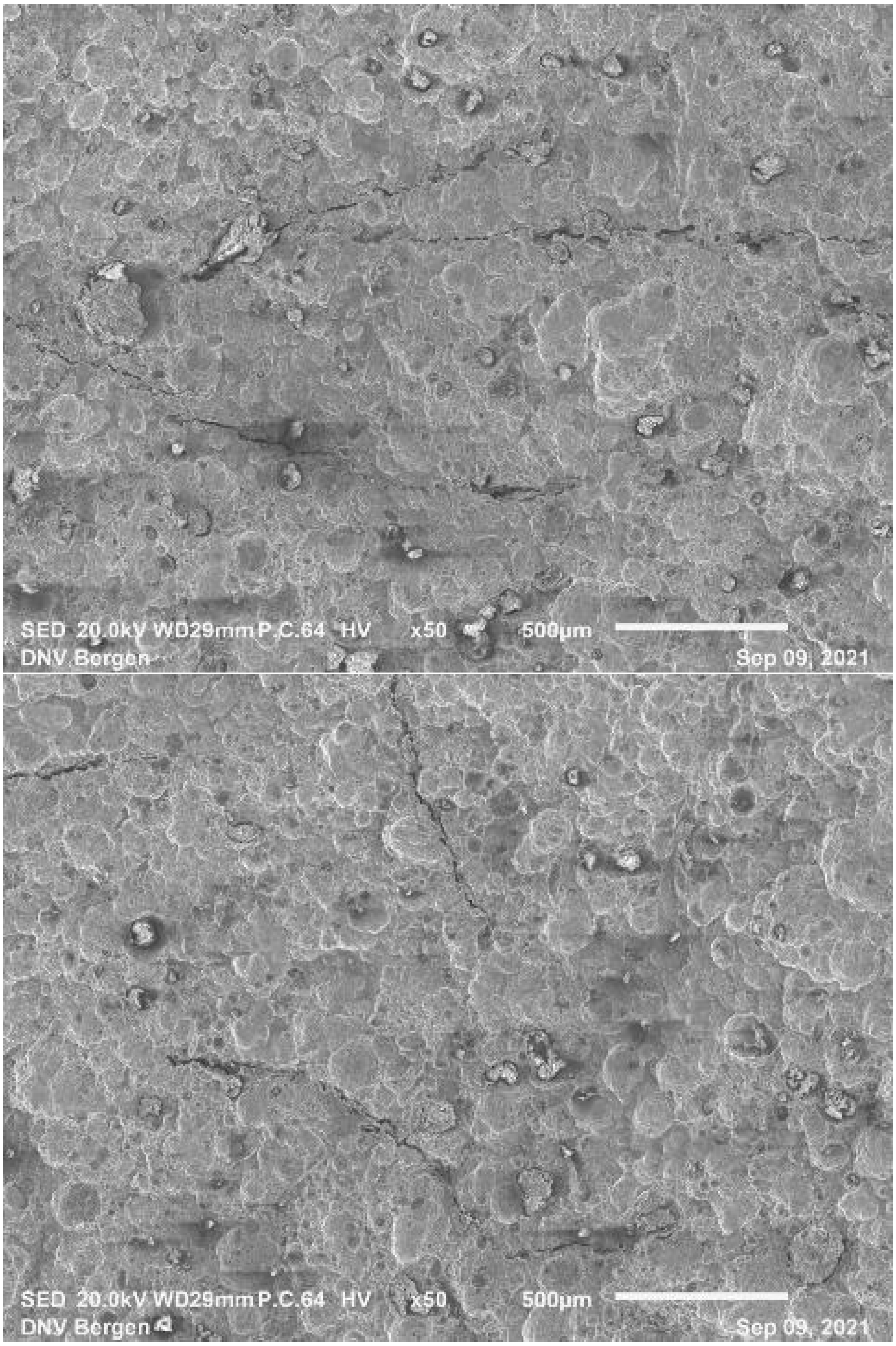



**Figure 5-9 Fracture A: Cracks in the chain link surface, below the crack initiation area.**

Figure 5-10 and Figure 5-11 shows the initiation area at low magnification. Some indication of possible beach marks are seen; however the fracture topography is mainly disturbed by corrosion. This is also shown in the close-up images showing representative features from the fracture topography, shown in Figure 5-13 to Figure 5-16.

Figure 5-12 shows the clear change from the more even inner fracture surface, to the outer and rougher surface.

In several of the close-up images, areas of intergranular cracking is observed.

Image courtesy of [Det Norske Veritas](#)

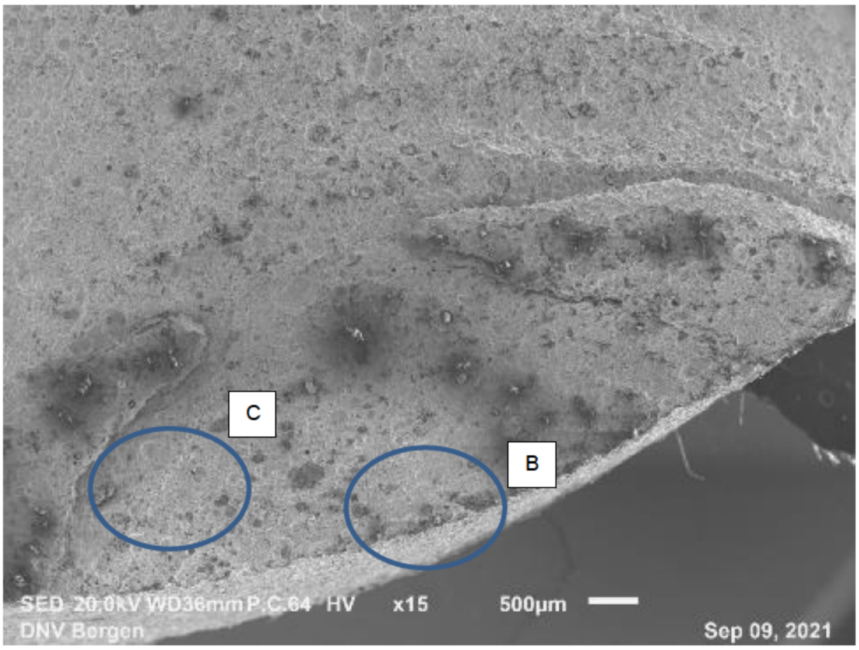



**Figure 5-10 Fracture A: Initiation area, right part.**

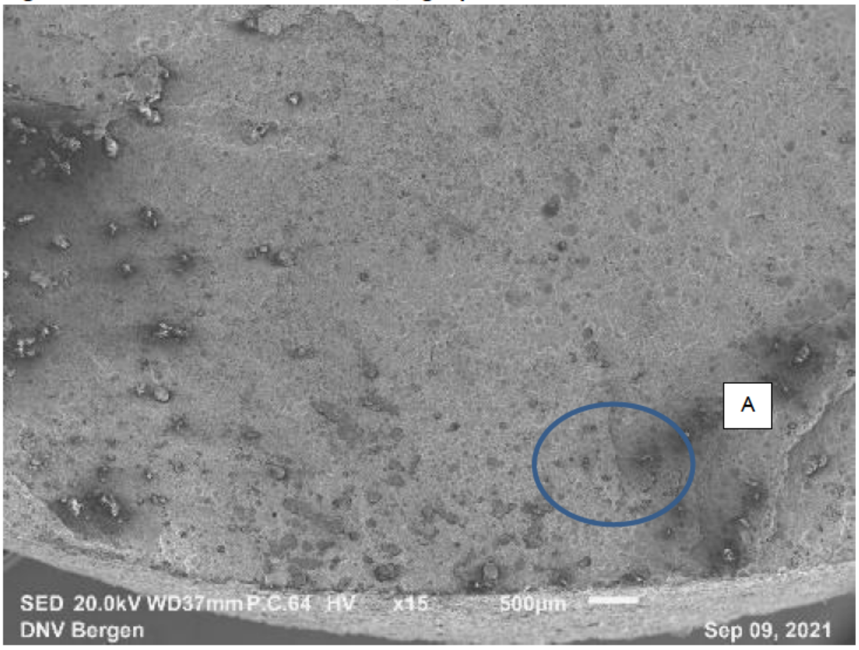



**Figure 5-11 Fracture A: Initiation area, left part.**

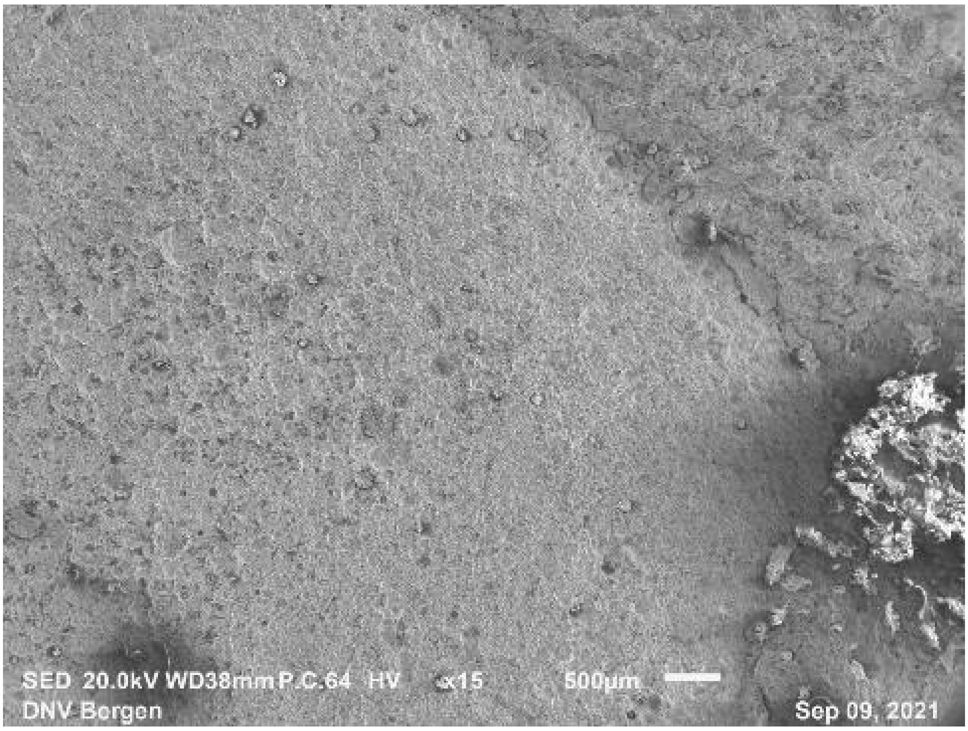
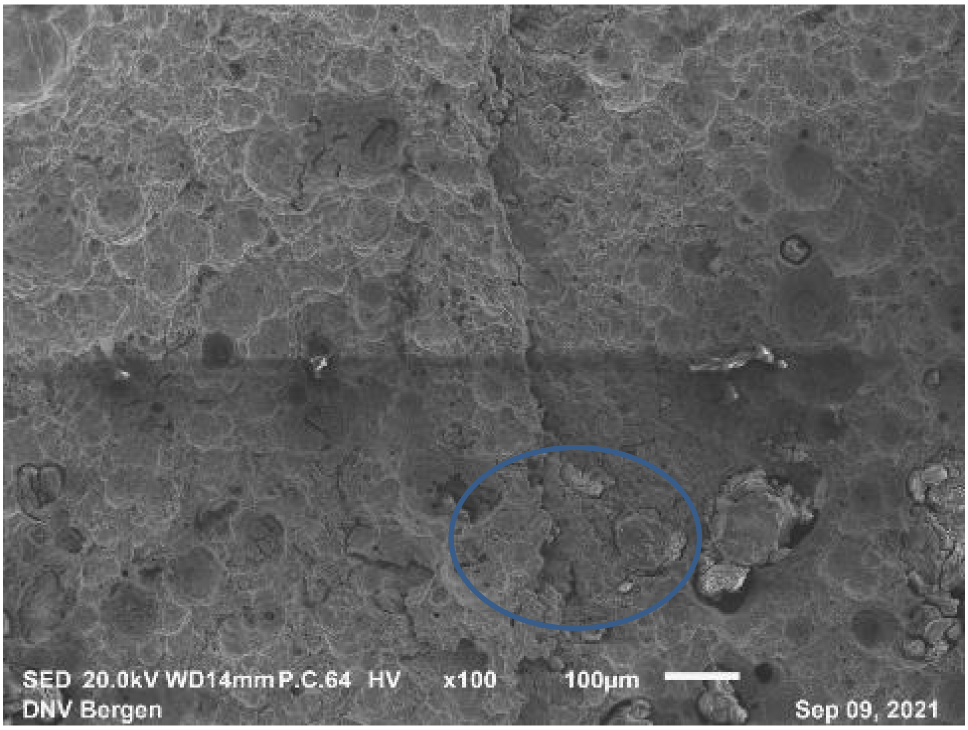



**Figure 5-12 Fracture A: Transition between mid part of fracture surface and outer part with rougher topography. Mainly corrosion is observed.**



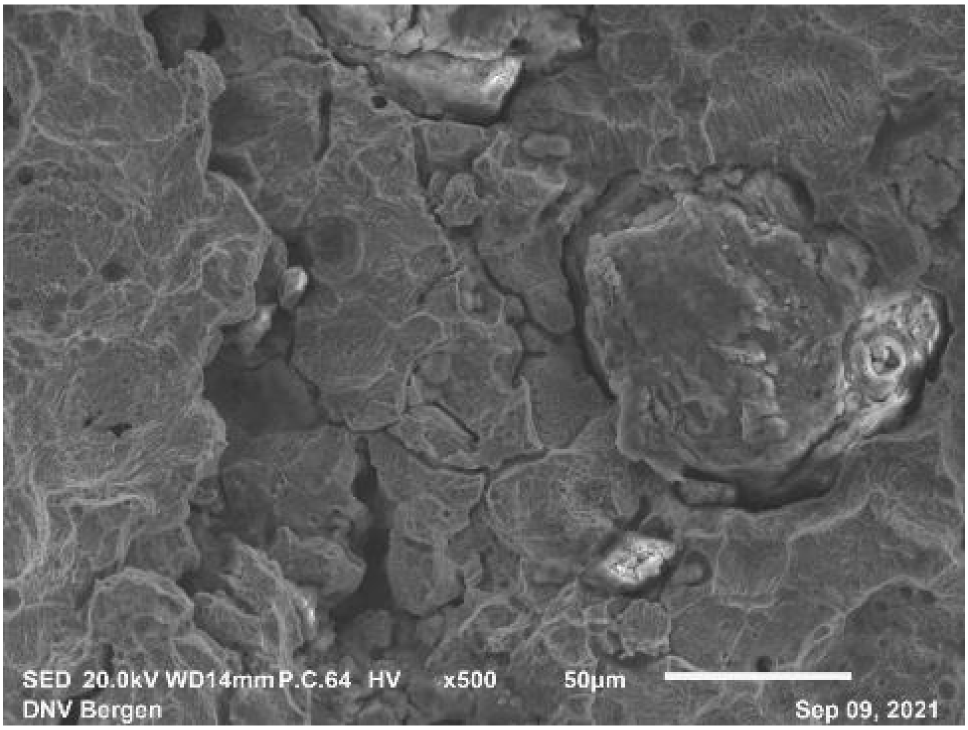




**Figure 5-13 Fracture surface A, area A: Intergranular cracks in fracture surface, along breakover line in initiation area. Corrosion and intergranular cracking are observed. The blue eclipse in the upper image shows the position of the lower image.**

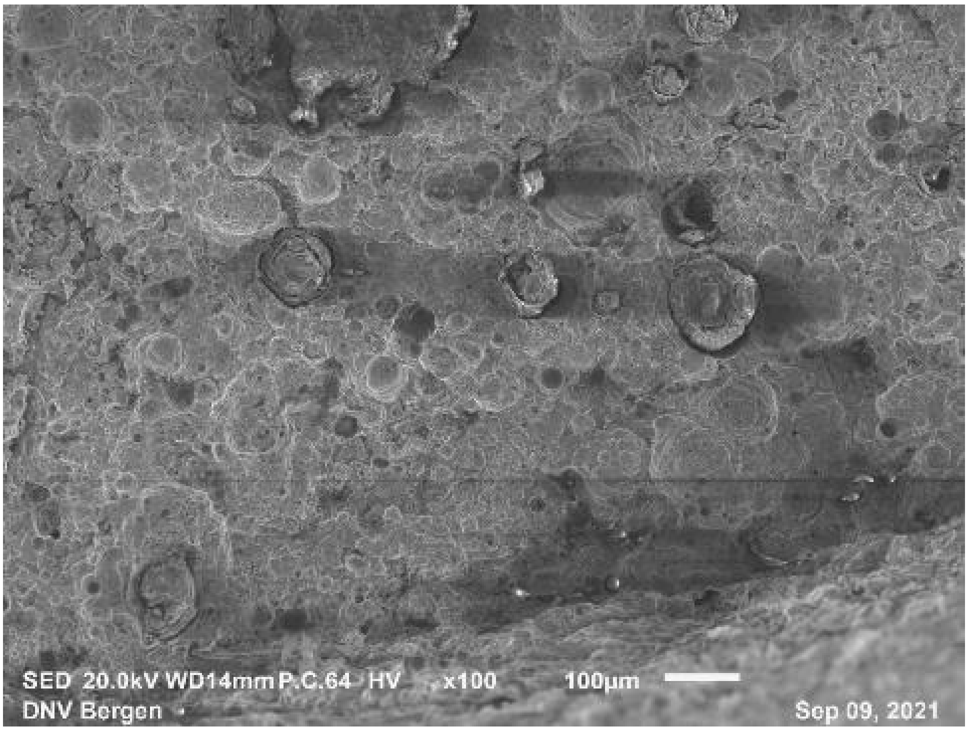
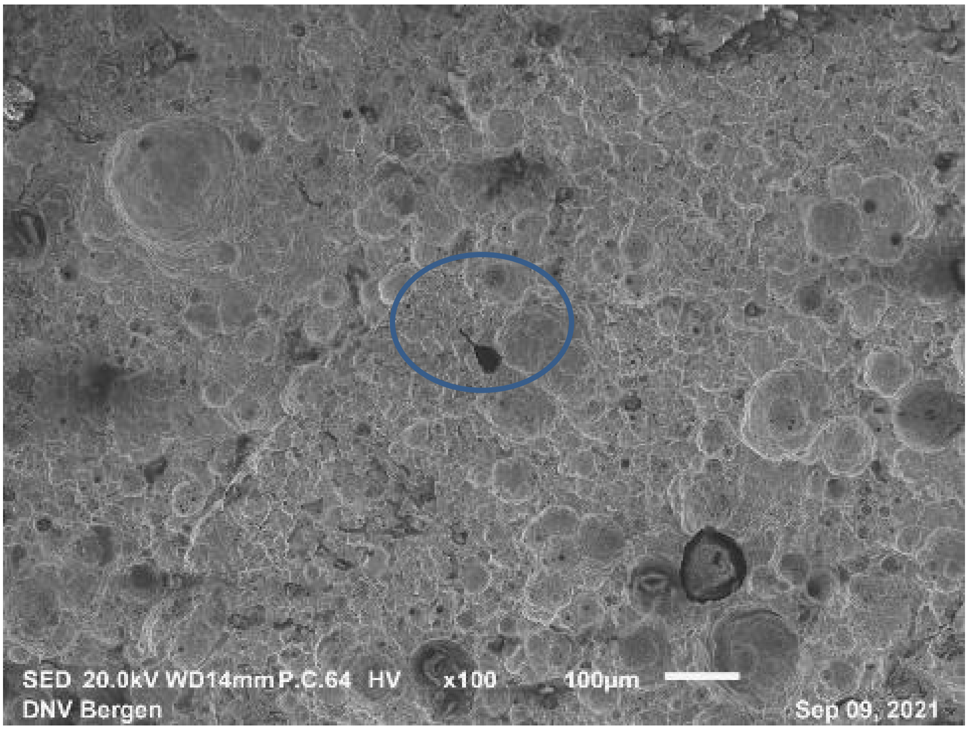



**Figure 5-14 Fracture A, area B: Crack topography at edge of initiation area. Dimples/corrosion is seen.**



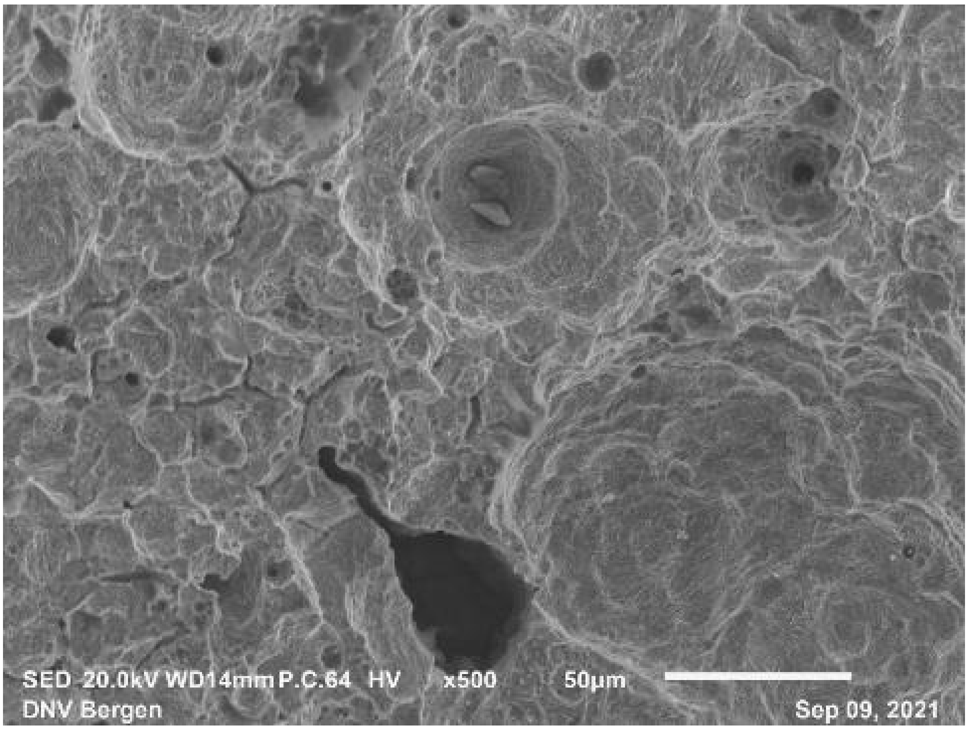
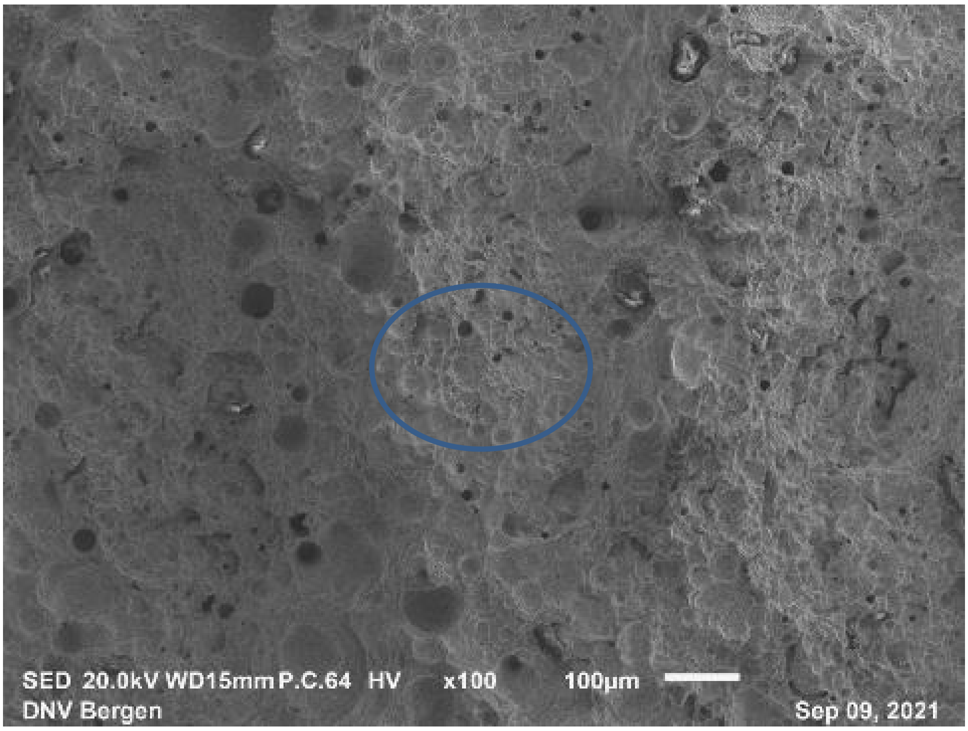




**Figure 5-15 Fracture A, area C: Possible beach mark in fracture initiation area. The blue eclipse in the upper image shows the position of the lower image.**



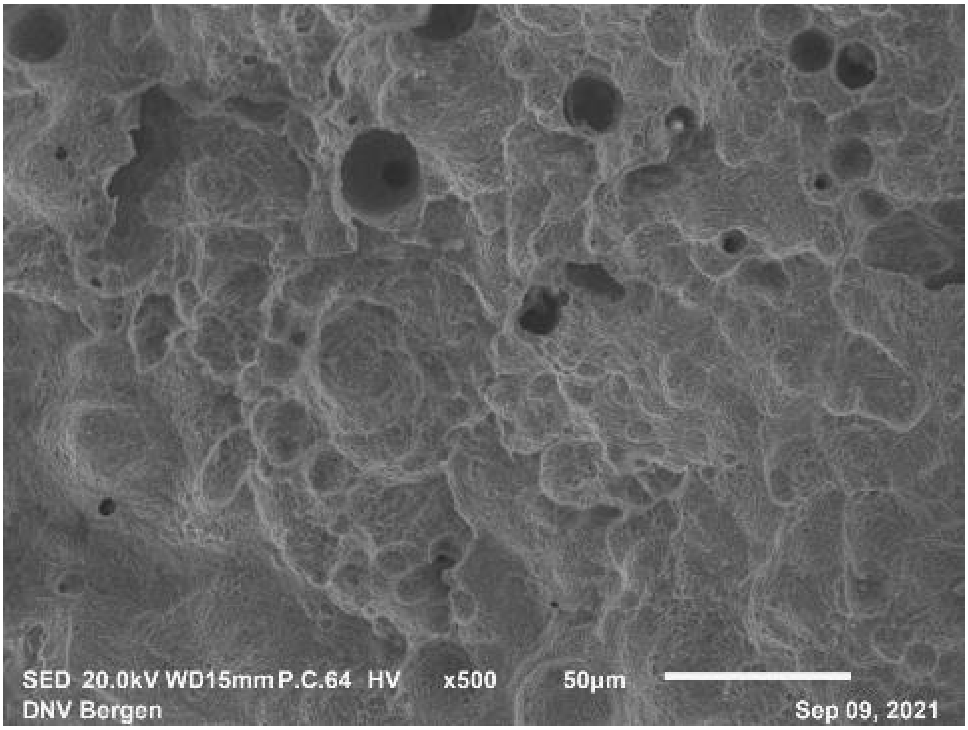




**Figure 5-16 Fracture A, area D: Outer part of fracture surface. See Figure 5-5 for position in overview image. The blue eclipse in the upper image shows the position of the lower image.**

### 5.2.3 Fracture B

An overview image showing fracture B after careful cleaning using inhibited hydrochloric acid, is shown in Figure 5-17. This fracture surface has a rather rough initiation area, as is indicated in Figure 5-17 and at higher magnification in Figure 5-18. The main part of the fracture surface has a typical river-pattern, as is shown at higher magnification in Figure 5-19. This crack has initiated approximately from the intrados (inner curve) of the chain. A shear lip is observed ca 90-180° from the initiation area, see Figure 5-20, and this is the last part of the chain link to have fractured.

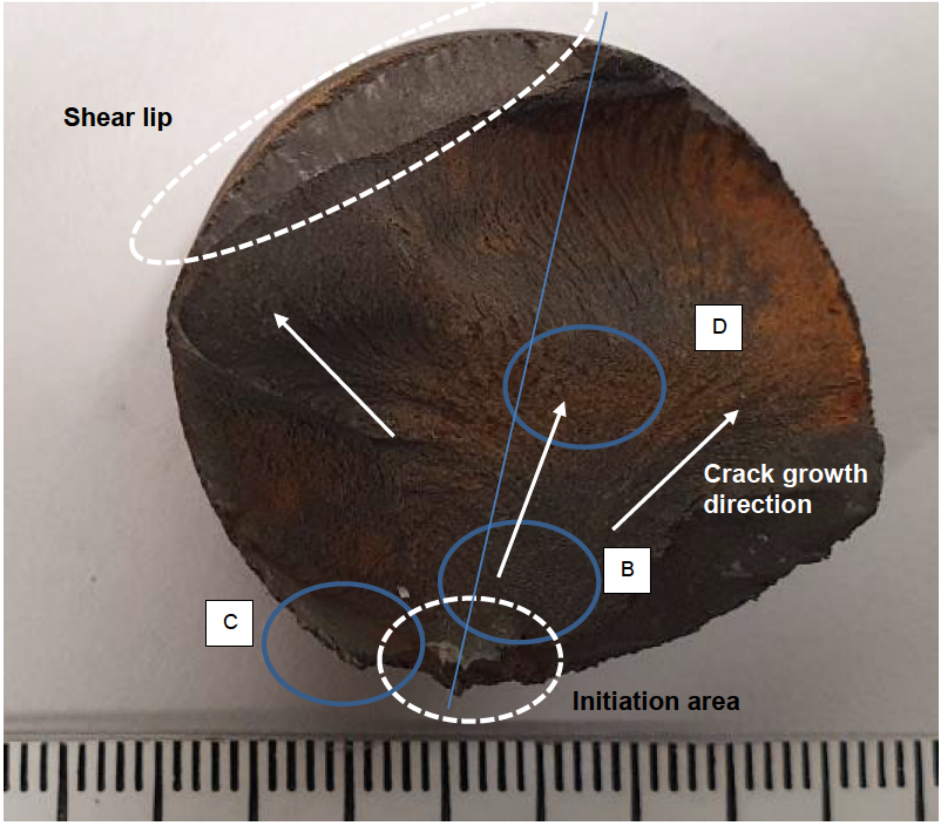



**Figure 5-17 Overview image showing fracture surface B after careful chemical cleaning. Fracture initiation area, crack growth direction and shear lip are included in the figure. The marked areas B, C and D refers to a SEM image. The approximate position of the line between the intrados and the extrados is included as a blue line, as the curvature of the link cannot be seen in the image.**


**Figure 5-18 Fracture B: Fracture initiation area. Several cracks observed. The marked area A refers to position of a SEM image.**

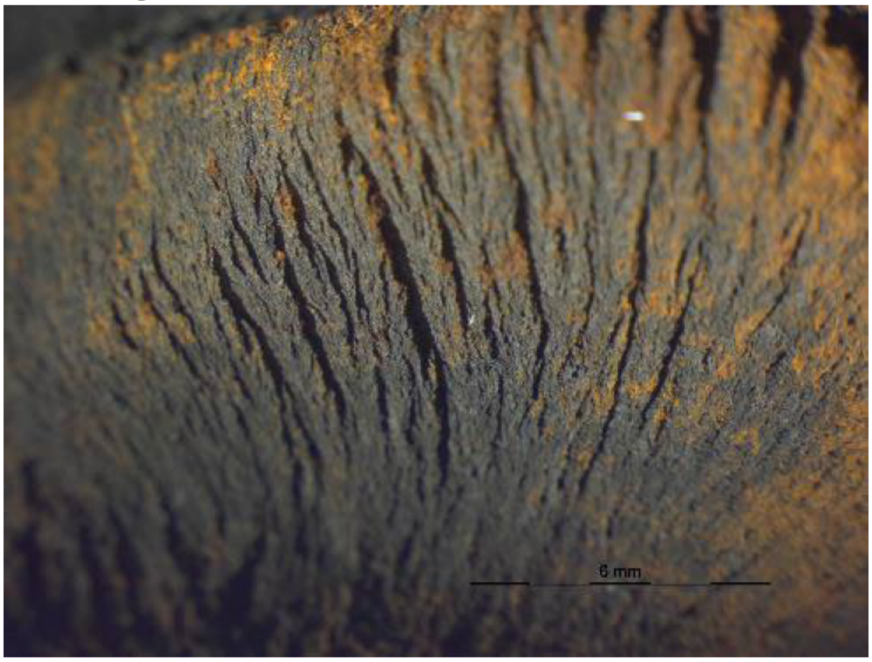



**Figure 5-19 Fracture B: Close-up of river pattern in main part of fracture.**

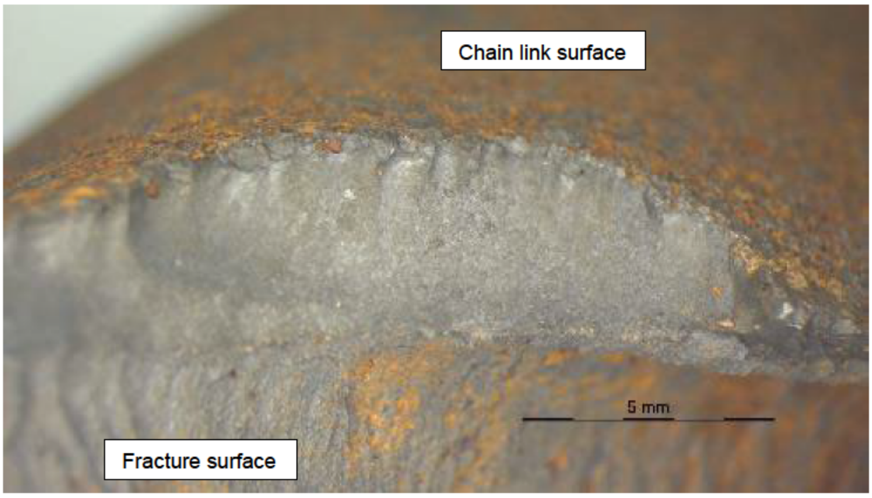



**Figure 5-20 Fracture B: Close-up of shear lip.**

## 5.2.4 Examination of fracture B, using scanning electron microscope

The fracture surface was examined at higher magnification using a scanning electron microscope. More cleaning using inhibited hydrochloric acid was performed to remove non-conductive corrosion products.

Overview images showing the initiation area and part of the main area with river pattern, is shown in Figure 5-21 and Figure 5-22, respectively. Cracks are seen in the initiation area, and to the left, there is an area with more cracks, Area C, as shown in Figure 5-23.

Close-up images from different representative areas are shown in Figure 5-24 to Figure 5-27. The fracture topography is a mixture of corrosion, and most likely a ductile fracture topography with dimples.

No cracks in the chain link surface close to the initiation area was observed visually.

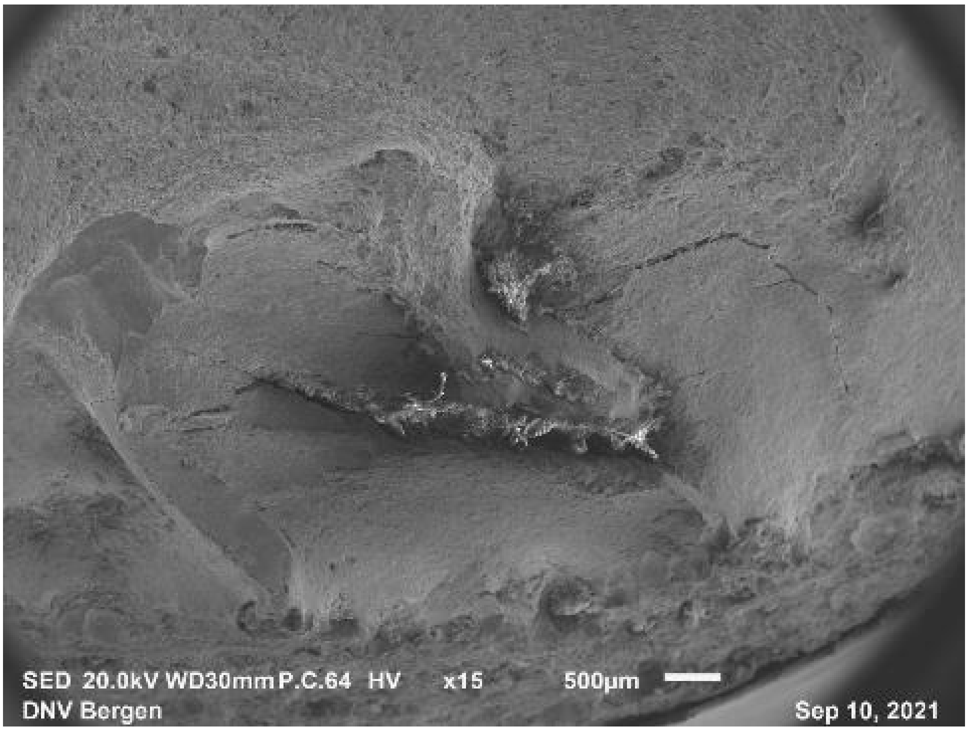



**Figure 5-21 Fracture B: Fracture initiation area.**

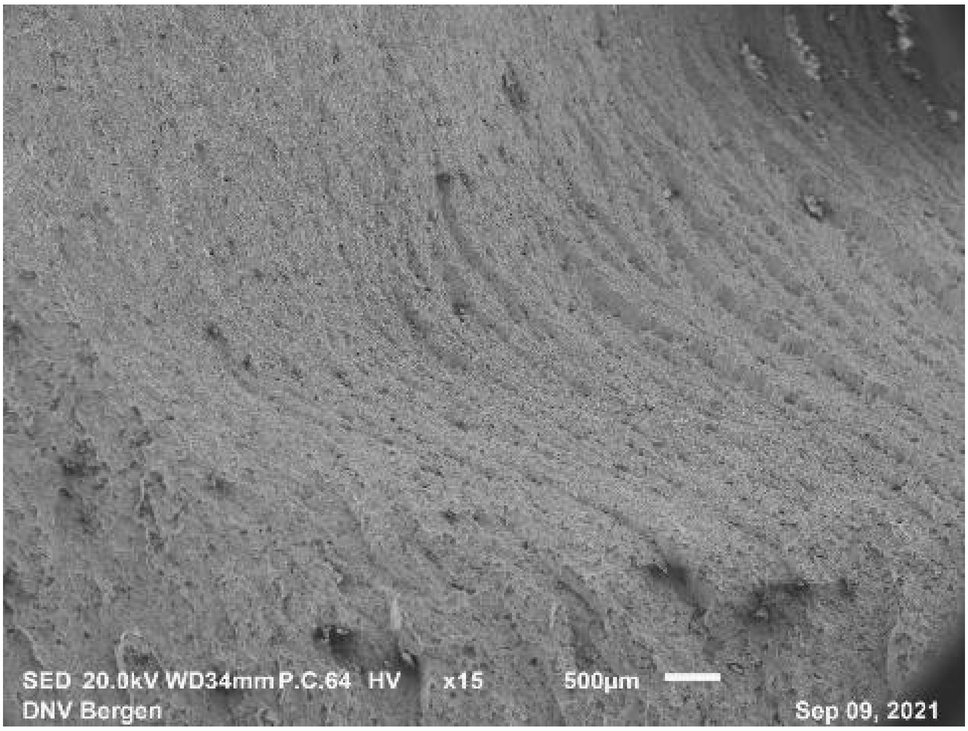



**Figure 5-22 Fracture B, area D: Main part of fracture surface, river pattern.**

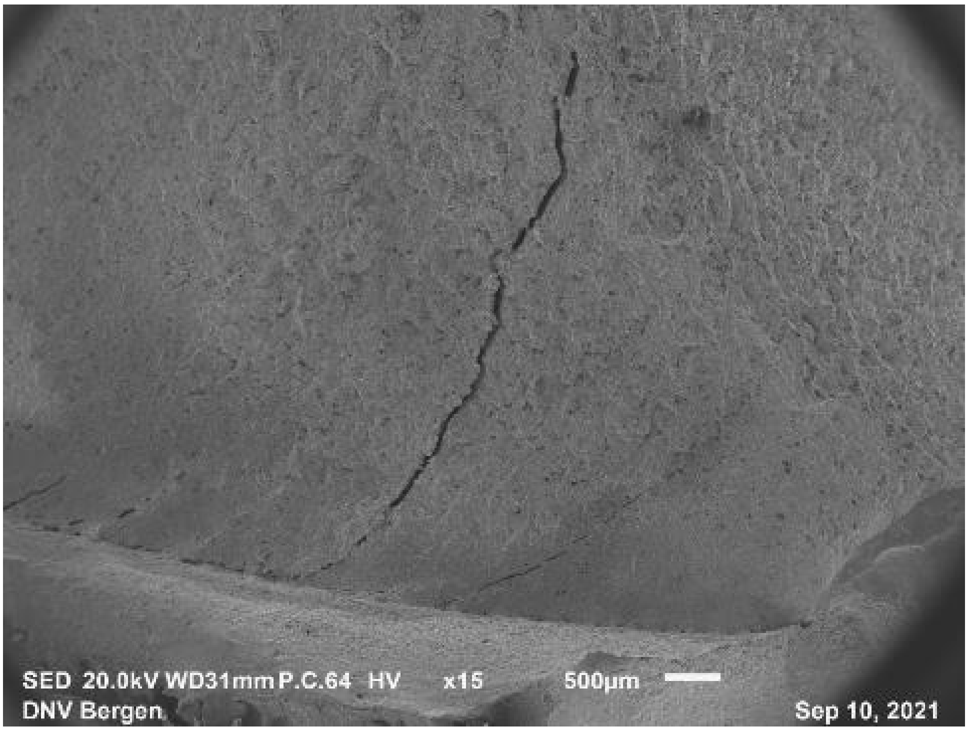



**Figure 5-23 Fracture B, area C: Area with multiple cracks, to the left of the initiation area.**

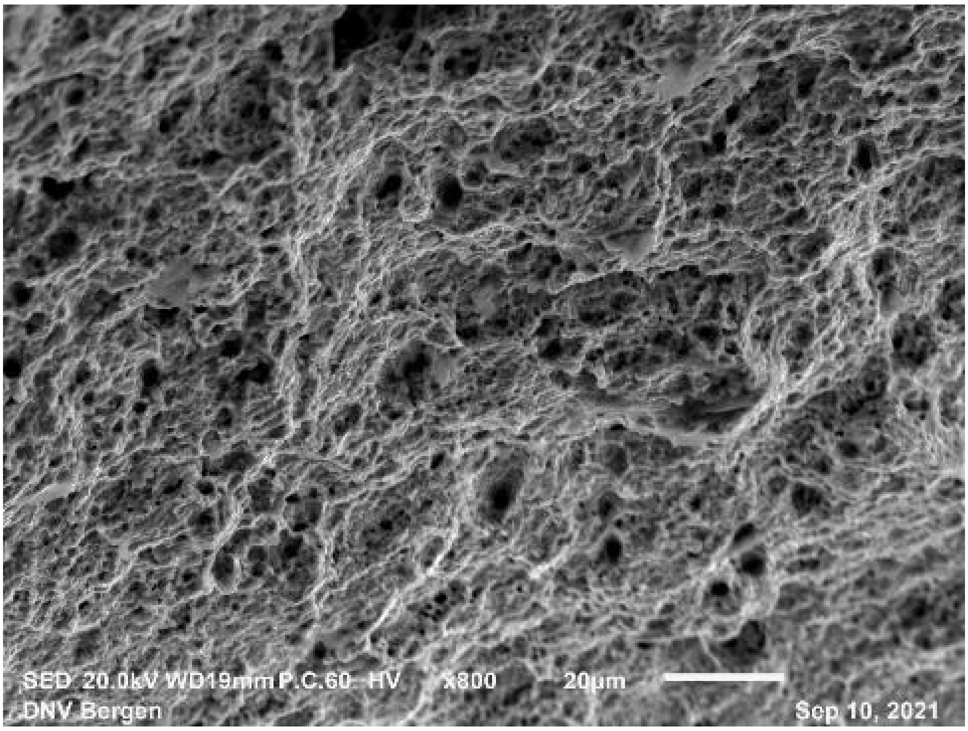



**Figure 5-24 Fracture B, area A: Right part of fracture initiation area. Corrosion and/or dimple fracture topography.**

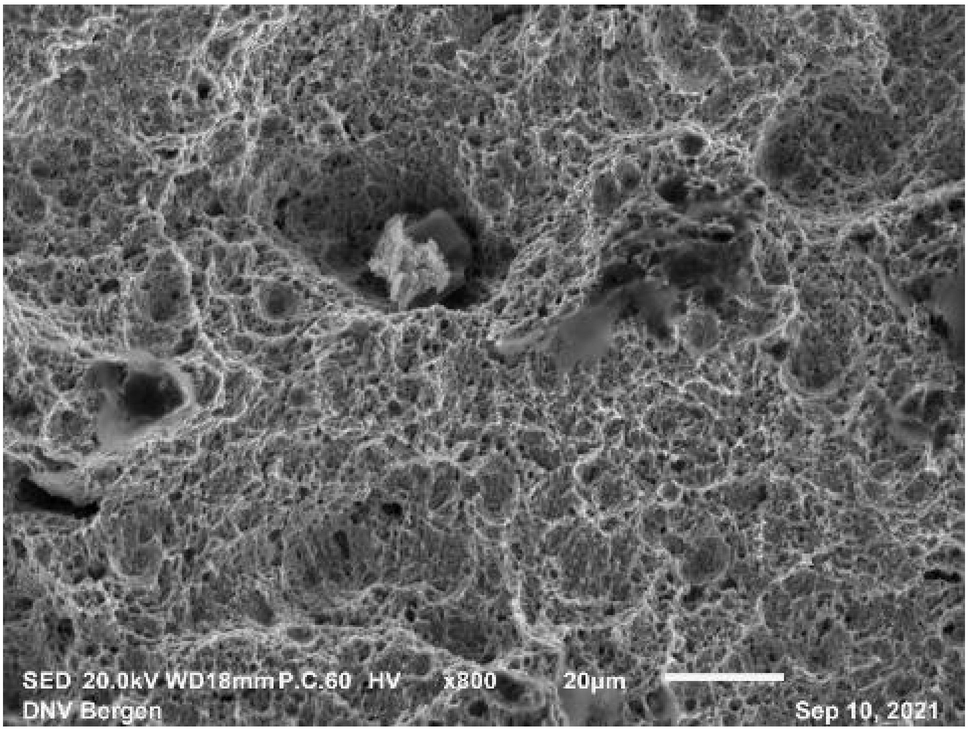



**Figure 5-25 Fracture B, area B: Main part of fracture surface, close to initiation area. Corrosion and/or dimple fracture topography.**

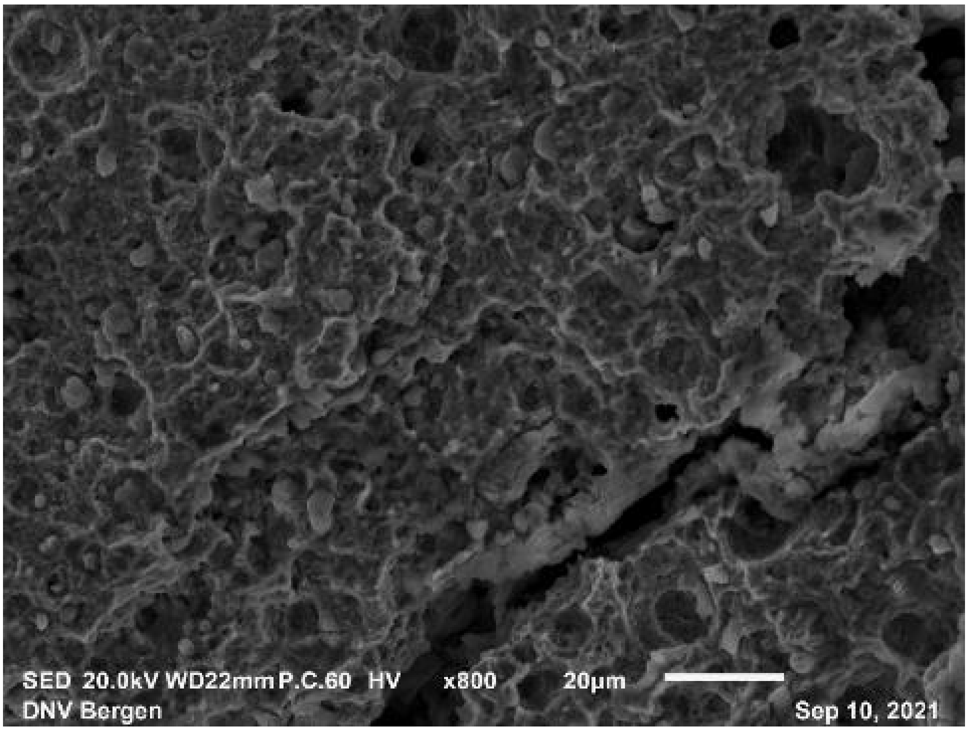
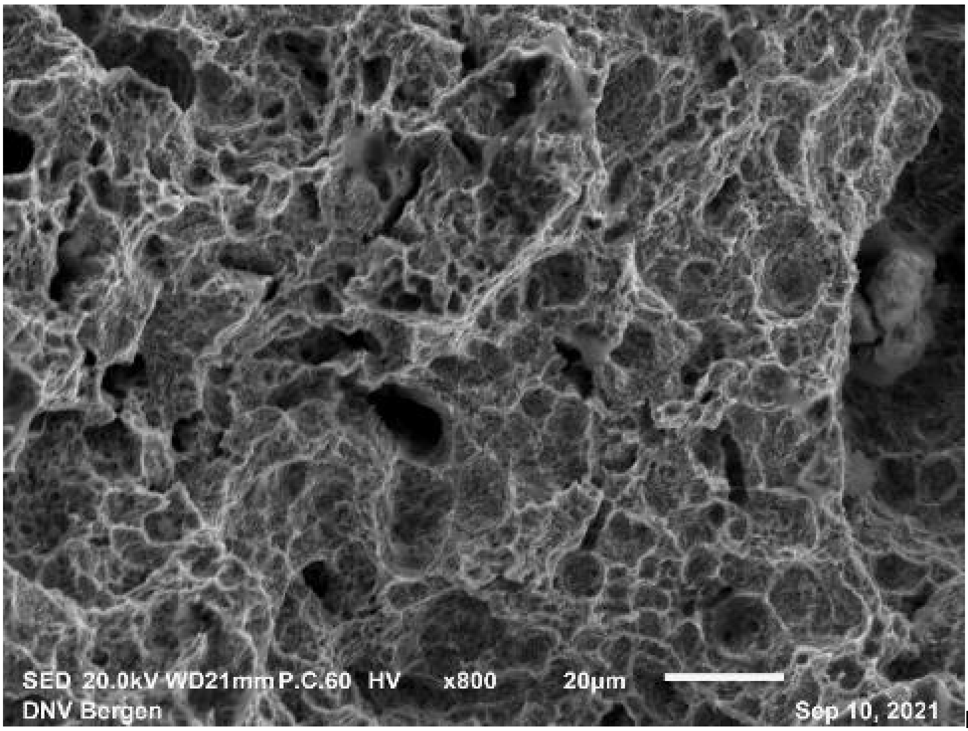



**Figure 5-26 Fracture B, area C: Area with multiple cracks, to the left of the initiation area. Corrosion and/or dimple fracture topography.**



D

**Figure 5-27 Fracture B, area D: Main part of fracture surface. Corrosion and/or dimple fracture topography.**

## 5.3 Metallographic examination

One cross section was cut through each of the fractures, through the crack initiation area. For fracture surface A, it was made sure that the cross section was made through the cracks seen on the link surface, shown in Figure 5-9.

Overview images showing the cross section through the initiation areas are given in Figure 5-28 and Figure 5-29. Two cracks parallel to the fracture surface, as well as one inhomogeneity perpendicular to the fracture surface is seen for fracture A. The inhomogeneity is found to be a longitudinal void in the material, see also Figure 5-32 , and is not believed to be related to the fracture.

For fracture B, several cracks are seen. These are however angled relative to the length direction, as shown in Figure 5-33.

The cracks seen in the initiation areas are shown at higher magnification in Figure 5-30 to Figure 5-31 (fracture A) and in Figure 5-33 (fracture B). The observed cracks close to both initiation areas have a jagged intergranular appearance, that are not typical for fatigue crack growth. These cracks were not detected using MPI, due to small size.

No changes in microstructure related to either of the fractures are seen, only a quenched and tempered microstructure, similar to the samples shown in Paragraph 4.7.1.

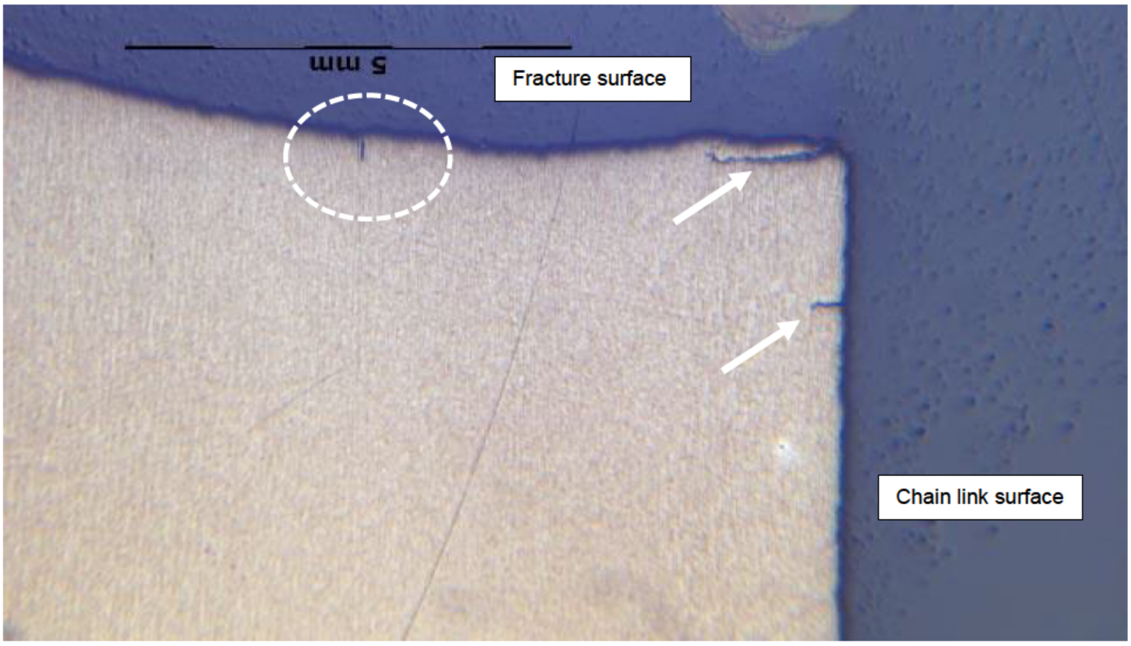



**Figure 5-28 Overview image showing the cross section through the initiation of fracture A. Two cracks parallel to the fracture surface (shown with arrows), as well as one inhomogeneity perpendicular to the fracture surface (marked by a dotted circle), is seen. The photo is rotated for more logical presentation.**

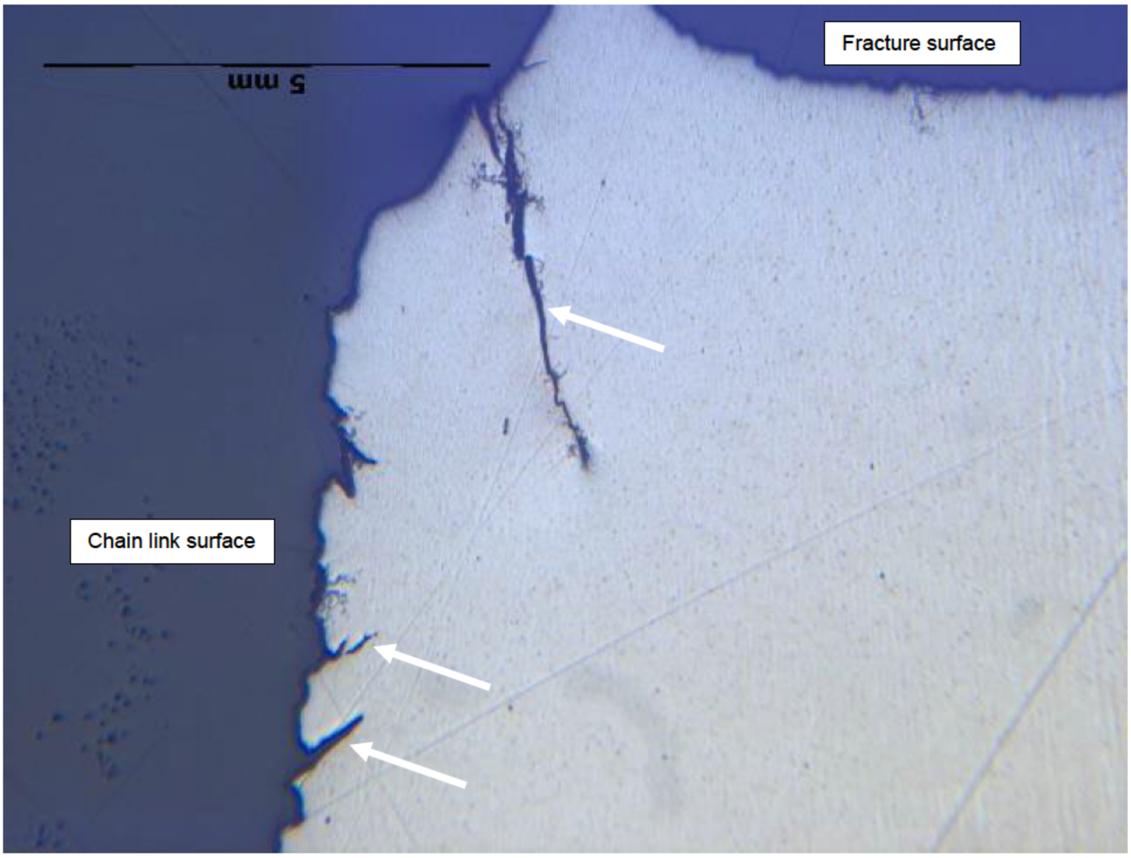



**Figure 5-29 Overview image showing the cross section through the initiation of fracture B. Several cracks (shown with arrows) close to the initiation area are seen. The photo is rotated for more logical presentation.**

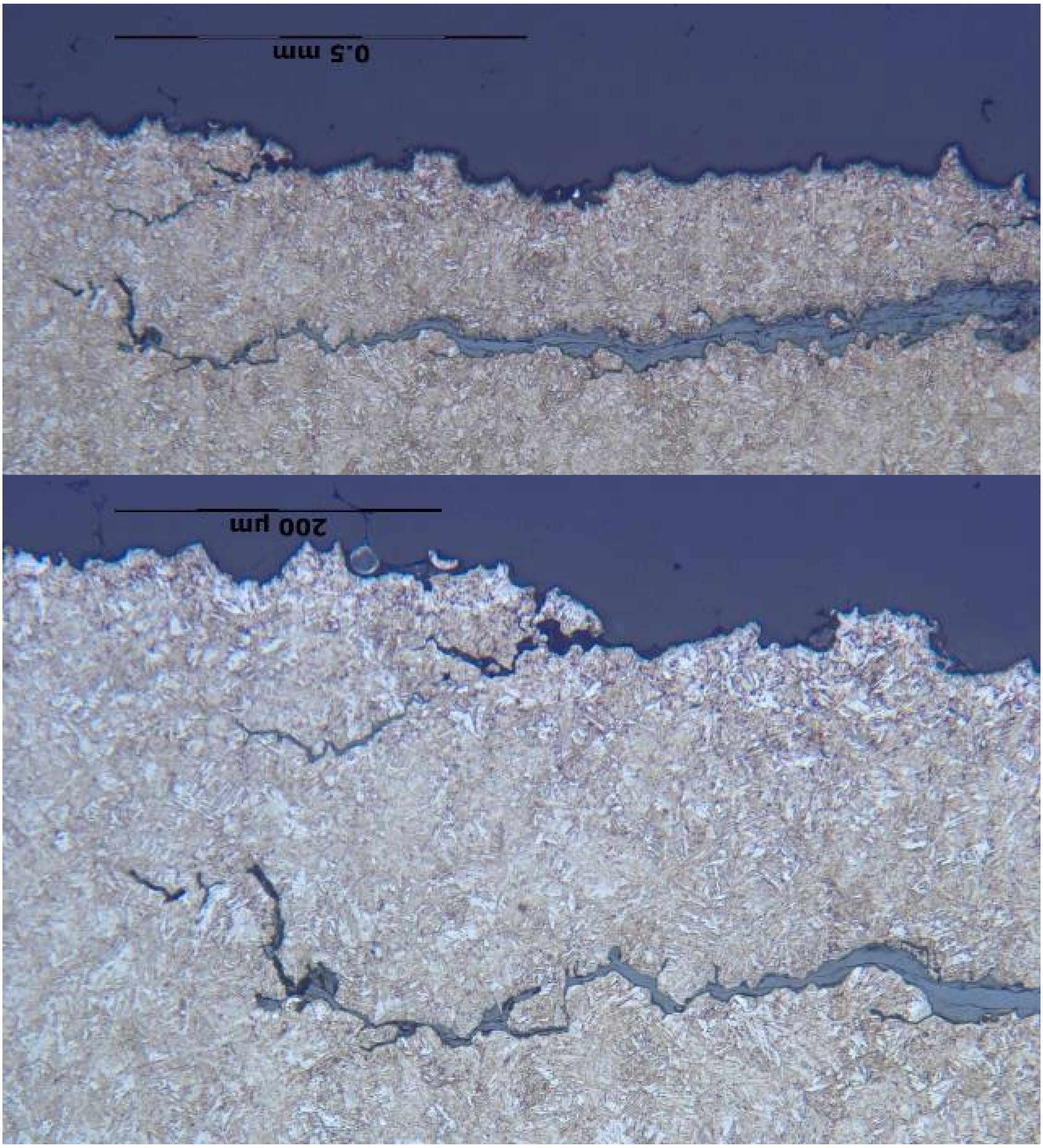



**Figure 5-30 Fracture surface A: Crack close to fracture initiation area. The photos are rotated for more logical presentation**

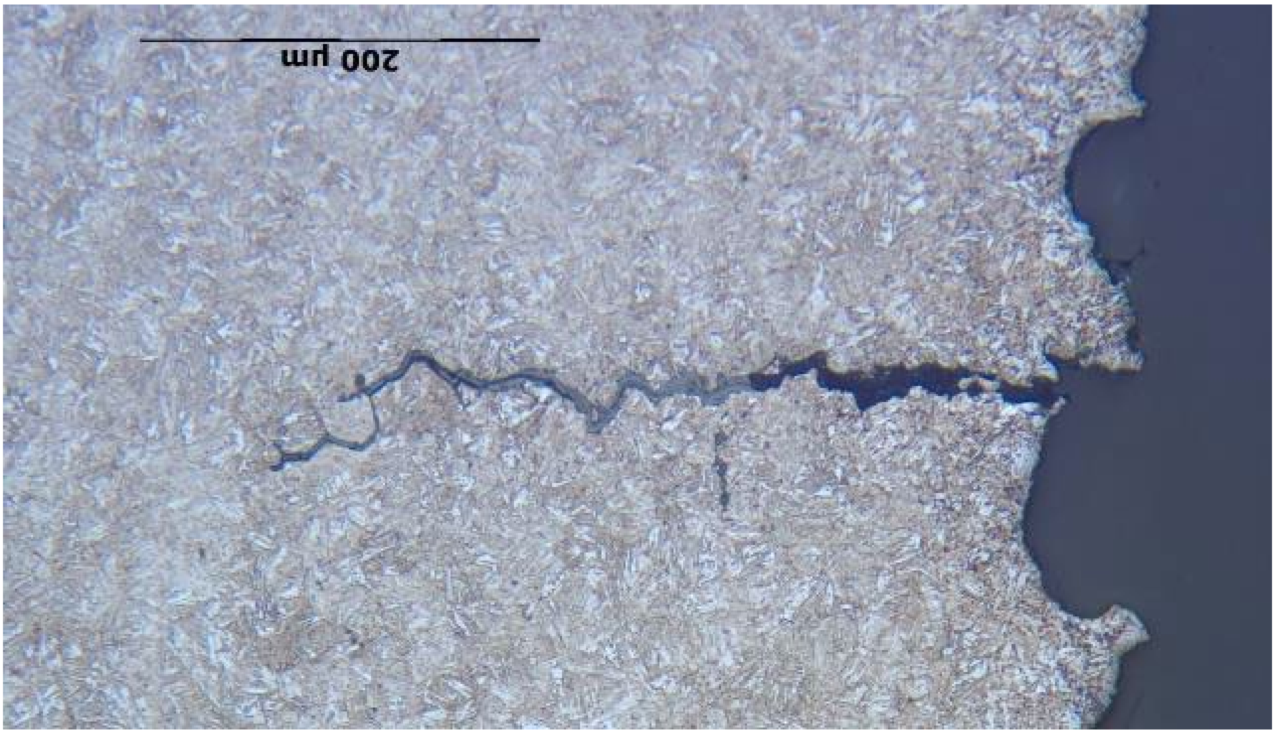



**Figure 5-31 Fracture surface A: Smaller crack close to fracture initiation area. The photo is rotated for more logical presentation**

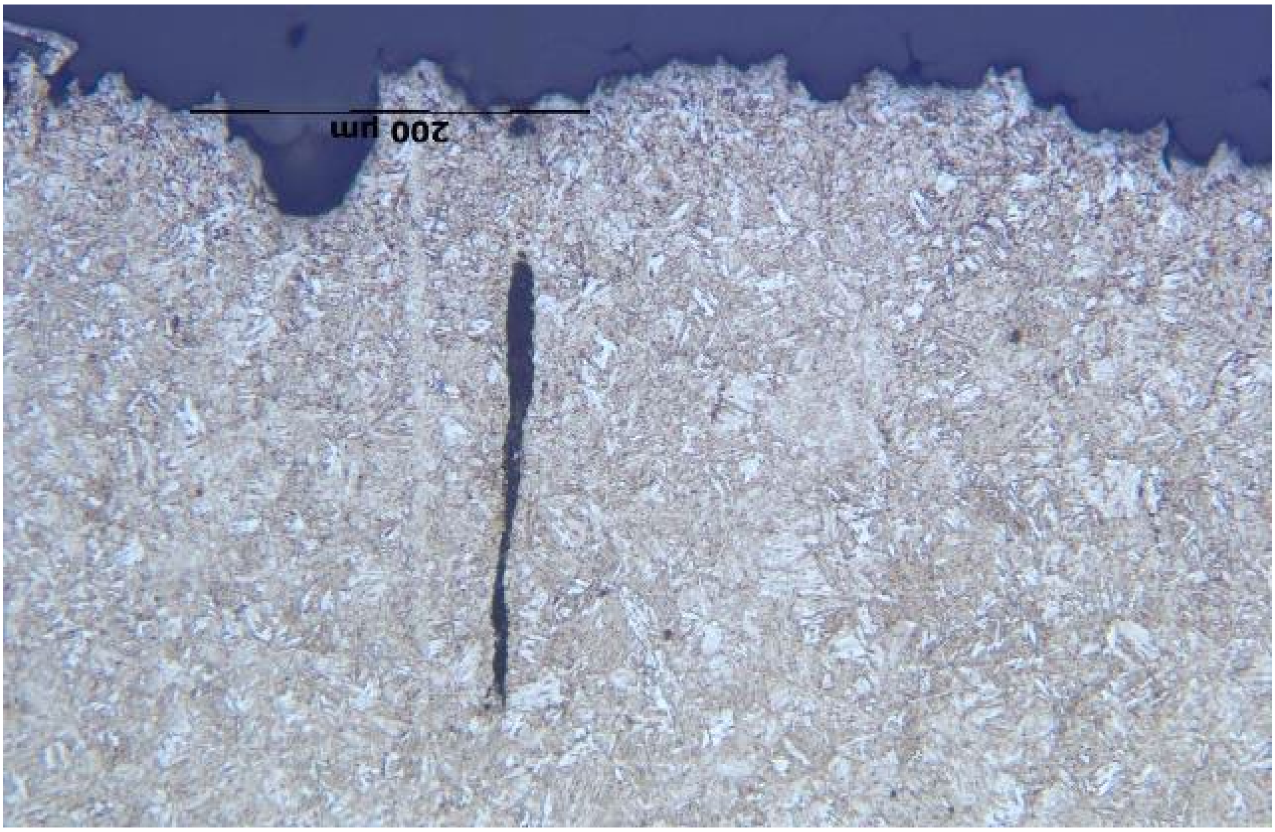



**Figure 5-32 Fracture surface A: Longitudinal void close to fracture surface. The photo is rotated for more logical presentation**

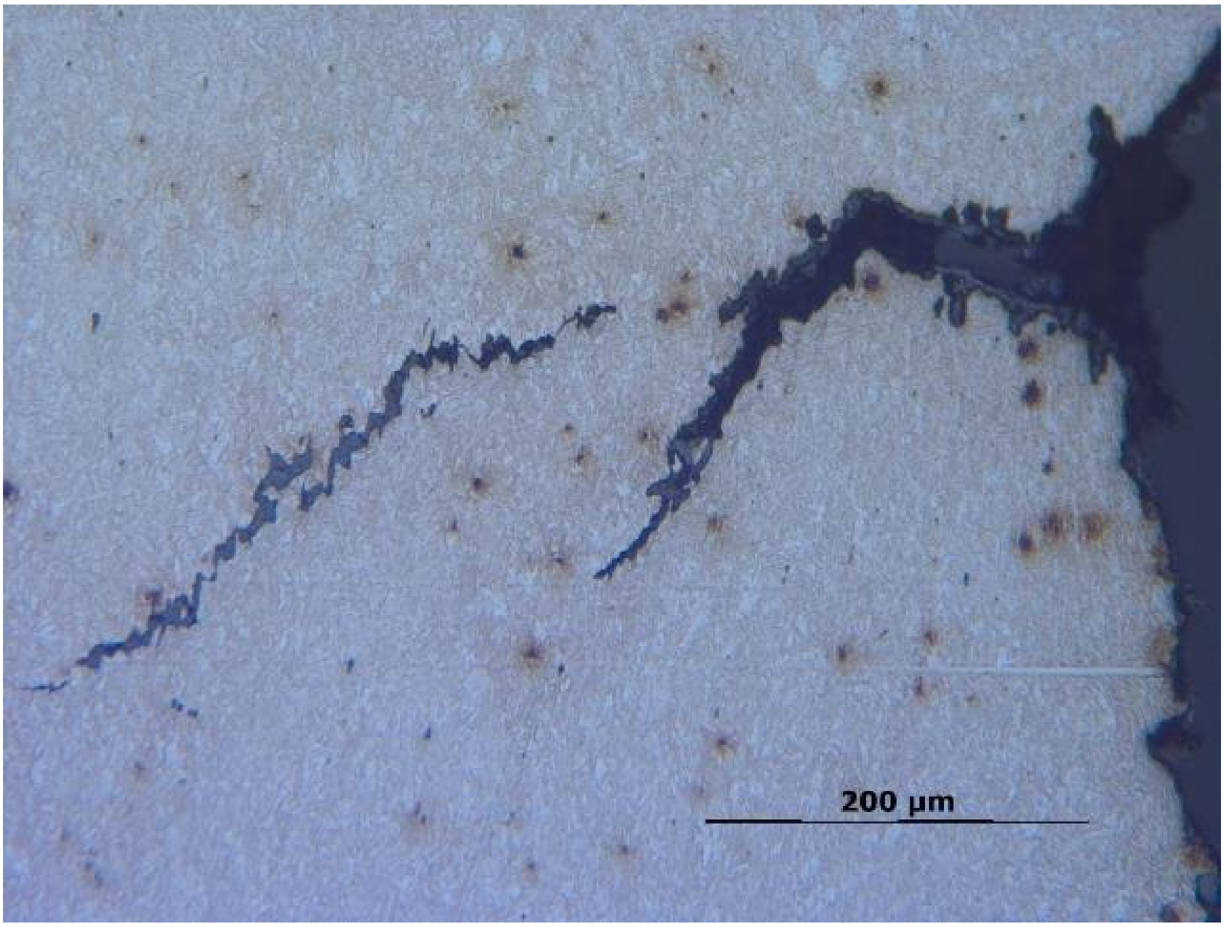



**Figure 5-33 Fracture surface B: Large crack close to fracture initiation area.**

## 5.4 Summary of examination and characterisation of chain material of fracture link

Samples for characterisation of chain material was cut from the fractured link as shown in Figure 5-4.

As reported in Paragraph 4, the following is summarised for the fractured link:

- NDT: No linear indications was seen on the fractured link, either visually or using wet-fluorescent MPI.
- The microstructure in the cross section away from fractures in the fractured link, shows a quenched and tempered microstructure, similar to the other chain links and close to the fractures.
- The measured hardness and estimated tensile strength in the fracture initiation area is somewhat lower compared to the values from the surface area of the cross sections on the other chain links. The hardness measured on the cross sections correspond well with the hardness of the other chain links (portside, starboard and reference chain).
- The chemical composition of the fractured link is similar to the chemical composition of the other chain links. The amount of aluminium is just below the requirements according to NS-EN ISO 818-2 /1/, however this is within the reported uncertainty of measurements. The manganese content is above the certificate value.

# 6 DISCUSSION

Based on the performed examination, the following is summarised

- Visual examination of the fractured chain as received shows extensive corrosion. No evident coating is seen. The chain has been in use approximately one year. The main cause of the corrosion is the marine atmosphere and direct contact with sea water. The original coating has flaked off and not given an effective corrosion protection.
- Corrosion is also seen on part of the crack surfaces of the fractured link from break load testing, indicating that the observed cracks are formed in service.
- Examination of both the starboard chain and the fractured portside chain shows no or limited plastic deformation. Also related to the fractures, no or limited plastic deformation is observed.
- Significant wear is observed in the chain interlink areas, indicating that there is movement between the links. The wear pattern is quite similar on both the starboard and the portside chain. Most wear is seen towards link 10, i.e., the shackle connecting the chain to the trawl, due to more movement in this area.
- The fractured link has been identified as the sixth link when counting from the steel wire rope end. According to the received images, the fractured link is positioned close to the pin of the derrick head, most likely experiencing some bending moment against the pin.
- Crack-like indications in a significant number of links is found, up to five cracks in one link. Cracks are found both in links that have been bent over the derrick heads and links that are considered to have been loaded along the main length direction. Examination of samples from break load testing showed that, in addition to the fractured chain link, at least one chain link has a crack that have propagated through the link thickness.
- Assessment of small cracks parallel to the main fracture shows intergranular crack propagation. Intergranular cracks are also seen in a few areas of the examined fracture surface A.
- Characterisation of the chain link material shows a quenched and tempered microstructure and chemical composition close to or within the relevant requirements. The manganese content is significantly higher than stated in the certificate, approximately 6 times the certificate value.
- Hardness measurement of four different chain links, in addition to the fractured link (also in fracture initiation area) shows average hardness values in the range of 419 to 438 HV10. Generally, the lower values are measured close to the surface, and the higher values are measured in the core/main part of the cross section.
- Tensile testing shows high tensile strength, with relatively good correspondence to the hardness measurements. The sample from the reference sample (unused chain) has higher tensile and yield strength and lower elongation and contraction than the sample from the fractured chain. For both tensile samples, the yield strength and tensile strength are close, with yield to tensile strength ratio of 0.990 (chain with fracture) and 0.998 (reference chain).
- Break load testing shows results significantly below MBL for both the used starboard chain length and for the unused reference chain length, without significant pre-existing cracks.
- The material of the derrick head is found to be a quenched and tempered alloy steel in the pin and a low-alloy construction steel for the cheek plate material. This is considered not to have had significant influence on the failure.

## 6.1 Direct cause of fracture

Based on the corrosion damage on the fracture surfaces, the fractures are believed to have started as cracks prior to the incident. This is also supported by a large number of cracks found in other chain links from both the starboard and the portside chain. When the cross section has been too small to withstand the loading, the final fracture has occurred, and the chain length has fractured. The loading has been a combination of tensile loading and bending from contact with the derrick heads.

The topography observed in cracks close to the initiation area of fracture A in the fractured link, indicates environmentally influenced cracking. The crack path is ragged and typically intergranular, i.e., follows the prior austenite grain boundaries instead of propagating straight through the microstructure. This is not as expected from fatigue crack growth, however, is typical for environmentally induced crack growth /11/. Based on the environment, it is most likely that the environmental effect is due to hydrogen, i.e., hydrogen embrittlement. Hydrogen embrittlement can occur for a material that experience a combination of the three factors /11/:

- Tensile loading
- Presence of hydrogen
- Susceptible material

All the chain links will experience tensile loading, both along the length direction, and from bending over the pin of the derrick heads.

Significant corrosion is observed both on the chain link surface and on the fracture surfaces. Hydrogen is normally formed during the corrosion process in a humid environment which is likely in this case. Other sources of hydrogen could be steel production, welding, electrolytic zinc plating or HDG (hot dip galvanizing) or cathodic protection, if relevant. Only hydrogen from steel production could be relevant in this case. No analyses of hydrogen content have been performed. Due to the time since the incident, a measured low hydrogen content could also be caused by hydrogen diffusion out of the material, hence would not be unambiguous. High strength (high tensile strength / high hardness) low alloy steel is considered susceptible to hydrogen embrittlement effects. The likelihood of cracking and fracture is difficult to quantify, but the likelihood is considered to increase with /11/:

- Increased tensile strength / hardness
- Reduced ductility
- Increased hydrogen content
- Increased tensile stresses

Material testing confirms both high tensile strength and hardness and low ductility, seen as high yield strength relative to the tensile strength. Low elongation is also seen. The mechanical properties are further discussed and compared to relevant standards in paragraphs 6.3 and 6.4

Due to the high strength/hardness and low ductility of the chain material and corrosion pits in the chain link surface that can act as local stress raisers, it is considered likely that the observed cracks in the chain material, are hydrogen-induced cracks.

These cracks can either grow by further brittle crack growth or be initiation points for fatigue crack growth. The topography of fracture A gives some indication of the latter mechanism, based on vague beach marks and ratchet marks / break-over lines. Based on the corrosive environment, corrosion is also believed to assist in the crack growth.

The high number of cracks in both used chains also indicate that the material is susceptible for crack growth.

## 6.2 Loading of chain

DNV has not received any quantitative information about the expected loads of the examined chain, only a qualitative description of the use. According to information from the client, the chain supports the weight of the trawl, the catch as it is lifted up, shock loading with frequent relief of loading due to the bobbing movement of the gear along the seabed, full load of the vessel tonnage if the gear gets snagged on the seabed etc. The derrick heads are found to consist of a quenched and tempered alloy steel in the pin and a low-alloy construction steel for the cheek plate material, and is not considered to have significant effect on the damage of the chain.

The examination of the pins in the derrick heads shows severe deformation/wear, caused by the contact with a chain with the relevant diameter. It is not known if the pin has been changed at the same time as the chain, or if the wear pattern can be from a previous chain. It is however considered likely that the significant deformation/wear can influence on the load distribution in the chain, i.e. that the load is distributed more into one leg instead of two of a chain link, or that the load on the steel wire rope side of the pin is lower than the load on the trawl side, due to the chain “hanging” on the pin. The fractured link is found to have been positioned at the pin, somewhat towards on the steel wire rope side. Link no. 4 on the starboard side, that fractured during the break load testing, and was found to have a pre-existing crack through the diameter, has been positioned on the steel wire rope side of the pin. Cracks are also found on links on the trawl side of the derrick pin.

The geometry of the system also gives bending loading of the chain links that are supported over the pin, and not pure tensional loading or tension/tension loading (repeated variation in loading due to wave movement) as a lifting chain onboard a vessel will normally experience. This would decrease the capacity of the chain part bent over the pin. The fractured link has most likely been positioned in contact with the pin, hence bending moment on this link is expected.

The break load testing shows the break load of the reference sample is low compared to the requirements, the result is 994 kN, i.e., 77% of the MBL. The used chain has a significantly lower break load, 223 kN compared to the required 1290 kN according to ISO 818-2 and ASTM A391 /1-2/. This shows that during use, even the starboard chain with a crack through the diameter has sufficient capacity to withstand normal loads, at least without additional bending moment. Based on this, it is not expected that the loading the chain will experience from normal use is high enough to overload a chain without cracks or other weaknesses.

The chain is also connected to a steel wire rope, with working load limit 8.4 tons. This steel wire rope is considered to be a weaker component compared to the chain. Assuming a safety factor of 5 would give a break load of the steel wire rope of 42 tons, i.e. 411 kN. This is around half of the break load of the unused chain, however higher compared to the used chain with multiple cracks, including one crack through the link thickness. Note that the capacity of the chain will be reduced by the bending over the pin of the derrick head.

## 6.3 Assessment of hardness of chain material

One of the important factors for environmentally induced cracking is high hardness /11/. The measured hardness of the material is in the range of 419 to 438 HV10, where the lower values are measured close to the surface, and the higher values are measured in the core/main part of the cross section. Based on NS-EN ISO 18265 /4/, this corresponds to Brinell hardness of 413 to 425 HB and estimated tensile strength of 1308 to 1344 MPa.

According to test certificate from the manufacturer, forwarded by the client (given in Appendix F), the expected hardness is 375 HB, corresponding to 380 HV10, according to NS-EN ISO 18265 /4/. Brinell hardness cannot be compared directly to Vickers hardness, however an estimated converted value for Vickers hardness is found, using NS-EN ISO 18265 /4/. The standards stated in the certificate does not give any requirements to hardness or tensile strength of the material, however, refers to mean stress at the breaking force (BF min) = 800 N/mm$^2$. The estimated tensile strength is significantly higher than this. This is as expected as this calculation is based on a cross section of two times the cross section of one chain leg and does not take the geometry of the crown into account.

Generally, a higher hardness corresponds to a higher break load, which is desired, however, a higher hardness also increase the probability of environmentally induced cracking. The recommended hardness is dependent on a number of factors, for instance loading and material.

Other relevant standards and their requirements for hardness are given below:

DNVGL-ST-E271: Offshore containers /6/:

In a guidance notes regarding lifting chain, the following is stated:

- For grade 8 chain, “components with hardness value 395 HV10 or lower will not normally require special consideration”
- For grade 10 chains, a number of requirements are given for accepting the use, among them “Hardness value does not exceed 410 HBW or 435 HV10”.

This means that the relevant chain would need special consideration for use in lifting of offshore containers, due to high hardness. It is considered that the environment is comparable, and the safety considerations should be similar, hence the standard is relevant for comparison.

NORSOK R-002, Lifting equipment /7/:

For equipment for general purpose lifting, normally onshore lifting and inboard lifting on an offshore facility, the general requirement for material grade is grade 8 according to European standards, i.e. NS-EN ISO 818 series, in this case, NS-EN ISO 818-2 /1/.

Other grades of similar or better quality are accepted, provided they satisfy requirements of a recognized standard applicable for lifting equipment and have documented Charpy-V impact testing.

No specific hardness requirements are given, however, for high strength chain, Charpy V impact testing is required. Qualification of chain is described to include the assessment of material ductility, impact toughness, material hardness, risk of hydrogen brittleness and sensitivity to corrosive environment., which all are relevant factors for the examined chain.

A general hardness requirement to avoid hydrogen embrittlement for materials used in oil and gas production systems according to ISO 21457 /8/, is a maximum of 350 HV10. Even though the type of components and area of use is far from the fractured chain link, possible failure mechanisms are similar, and hence the requirements should be considered relevant for the use of high-strength chain.

## 6.4 Assessment of yield strength / ductility of chain material

Tensile testing shows low ductility and extremely high yield to tensile strength ratio for the tested samples, being 0.99 (chain with fracture) and 0.998 (reference chain). Low ductility is another factor that increased the susceptibility for environmentally induced cracking.

The standards stated in the certificate does not give any requirements related to ductility, yield to tensile strength ratio or similar.

Other relevant standards and their requirements for yield to tensile strength ratio are given below.

According to a guidance note in DNV-OS-E302 /9/, the typical (recommended) yield to tensile strength ratio for mooring chain is in the range of 0.85 to 0.95. The range of yield to tensile strength ratio, would give a recommended yield strength in the range of 1140-1274 MPa for the sample from the fractured chain (tensile strength of 1341 MPa) and in the range of 1195-1336 MPa for the reference sample (tensile strength of 1406 MPa).

A requirement given in NS-EN ISO 13628-7 /10/, for carbon and low-alloy steel used in completion and workover riser system in the petroleum and natural gas industries, is maximum yield to tensile strength ratio of 0.92.

The obtained yield to tensile strength is considerably higher than the examples of maximum requirements.

## 6.5 Actual break load

The actual break load of the unused reference chain is significantly lower compared to the requirements according to the certificate, the results presented in the certificate and the requirements given in standards that the certificate refers to /1,2/. It is not believed that the low break load is related to significant cracks in the chain links, as no visual indication of cracks were found by non-destructive testing prior to break load testing, and also, the position and appearance of the fracture from testing is typical for overload fractures. Visual examination of the fracture surfaces of the break load test sample shows no indication of pre-existing cracks, however smaller cracks not visible to the naked eye could be present.

The required proof load of the chain is 804 kN, according to NS-EN ISO 818-2 /1/. The actual break load (994 kN) is higher than this and based on the curve from break load testing, the plastic deformation has just started at 804 kN and is considered to be minor.

Low actual break load is not expected based on the high hardness of the material, as tensile strength and hardness are more or less proportional properties, hence properties as ductility, yield to tensile strength ratio, etc. are believed to explain the low break load, not a low tensile strength.

It is considered likely that the fracture of the chain is not directly related to the low ductility, only through the higher susceptibility of hydrogen-induced cracking. For the current use and typical loads, it is not considered likely that the chain would have fractured in tensile overload, ref. the starboard chain where that have been in use with a through-thickness crack. However, for a higher utilization of the chain, this could have serious consequences in the form of premature fracture, as seen in the break load testing.

## 6.6 Assessment of properties of chain material

The examination has shown deviations from the certificate and/or requirements according standards referred to in the certificate /1,2/:

- Break load significantly below what is stated in the certificate and requirements according to the referred standards /1,2/
- Manganese content significantly above what is stated in the certificate

In addition, observations that can give increased risk of environmentally induced cracking are identified:

- High yield to tensile strength and low elongation (compared to requirements given for high strength mooring chain /9/)
- High hardness. The hardness is high compared to the typical value stated by the manufacturer (ref. Appendix F)

For the latter findings, there are no requirements according to the standards referred to in the certificate.

For the mechanical properties, all the observations correspond to each other, and are related to the heat treatment of the chain. The material has been through a quench and temper heating process. The high hardness and low ductility properties indicate that the tempering part of the quench and temper heating process has not been successful. This is also supported by the somewhat lower hardness close to the surface compared to the higher values in the core/main part of the cross section, i.e. better tempering on the outside.

The visual appearance of the microstructure is as expected, a quenched and tempered microstructure, however large differences in mechanical properties can be found without a clear difference in the visual appearance of the microstructure.

The manganese content could influence on the response of the chain material from the heat treatment. Generally, manganese increases hardenability and increases tempered hardness /13/. Manganese can also contribute to tempering embrittlement that reduce impact toughness /12/.

The actual breaking load measured, is significantly lower than the test results stated in the certificate, and the manganese content is significantly higher compared to the certificate. The measured hardness is also higher than the typical value stated by the manufacturer (ref. test certificate from the manufacturer, forwarded by the client, given in Appendix F). This indicates that there are higher variations in the properties of the chain, than is identified by the quality control of the manufacturer.

# 7 RECOMMENDATIONS

Generally, a Grade 8 chain is considered by the industry to be appropriate for lifting applications in marine environments. However, the Grade 8 quality requirements do not include a maximum hardness / maximum tensile requirement or requirements to ductility. Hence, additional requirements are included in several standards, especially for even higher strength steel, see discussion above.

Materials with hardness higher than 350 HV10 should be considered susceptible to hydrogen embrittlement and it should be considered good practice to limit the use of these high strength materials in critical lifting / load bearing applications in marine atmosphere and submerged applications. Post manufacturing baking to remove hydrogen introduced through the manufacturing process should also be considered good practice /8,11/.

Also, the Grade 8 quality requirements do not include requirements to ensure good ductility of the chain material, for instance yield to tensile strength ratio. The extremely high yield to tensile strength ratio of the chain is assumed to have large influence on the susceptibility of hydrogen-induced cracking and hence contribute to the failure. For a chain with a higher utilization, these properties could also have serious consequences in the form of premature fracture, as seen in the break load testing. Hence, measures should be taken to ensure increased ductility.

To prevent equivalent failures in similar applications in the future, the following preventive measures are recommended:

- It is recommended to initiate actions with regard to qualification of the fabrication process, to ensure a consistent quality of lifting chain. The large variation in chain properties indicate variation in the fabrication.
- It is also recommended to include test scope and acceptance criteria for mechanical properties for chain material, that are suitable to avoid failure mechanisms as describe above. This should cover both hardness/strength and ductility.

A preventive measure could also be regular inspection of the chain. However, the effectiveness of this could be limited due to a rough and corroded surface where detection of cracks will be difficult. It should also be considered if inspection is cost-effective, if the chain needs to be dismantled and properly cleaned to do a proper inspection. The short time in service for the examined chain also indicate rapid crack growth.

# 8 REFERENCES


/1/ NS-EN ISO 818-2: Short link chain for lifting purposes – Safety – Part 2: Medium tolerance chain for chain slings – Grade 8, 1996 (2008).

/2/ ASTM A391: Standard Specification for Grade 80 Alloy Steel Chain, 2021.

/3/ NS-EN ISO 6507-1, Metallic materials – Vickers hardness test – Part 1: Test method, 2018.

/4/ NS-EN ISO 18265, Metallic materials – Conversion of hardness values, 2013.

/5/ NS-EN ISO 6892-1, Metallic materials – Tensile testing – Part 1: Method of test at room temperature, 2019.

/6/ DNVGL-ST-E271: Offshore containers, 2021

/7/ NORSOK R-002, Lifting equipment, 2017.

/8/ ISO 21457, Petroleum, petrochemical and natural gas industries – Materials selection and corrosion control for oil and gas production systems, 2010.

/9/ DNV-OS-E302: Offshore mooring chain, 2021.

/10/ NS-EN ISO 13628-7: Petroleum and natural gas industries — Design and operation of subsea production systems — Part 7: Completion/workover riser systems, 2005.

/11/ ASM Handbook, Volume 11: Failure analysis and Prevention, 2002: Hydrogen damage and embrittlement.

/12/ Solberg, J. K.; Teknologiske metaller og legering; NTNU, 2011. (Translated to «Technological metals and alloys»)

/13/ ASM Handbook, Volume 4D: Heat treating of irons and steels, 2014: Heat treating of low-alloy steels.

Image courtesy of Det Norske Veritas

DNV

# APPENDIX A
## Chain certificate

Image courtesy of Det Norske Veritas

DNV

FASING S.A.

INTEGRATED QUALITY AND ENVIRONMENT MANAGEMENT SYSTEM

TÜV NORD Polska

PN-EN ISO 9001:2009; AC090 100/1267/64/2016
PN-EN ISO 14001:2005; AC090 104/1267/64/2016

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SERWIS tel. +48 32 735 00 00 w. 487, 489


| INSPECTION CERTIFICATE No.: | E-118/2019 | "Type 3.1" acc. to PN-EN 10204 |
|---|---|---|

**Chain / Type (Designation)** 32 x 96 (size) | 8 (grade) | 2 strands x 50 m (other) | 63200081 (catalogue No.)

produced acc. to EN 818-2 (standard) | - (technical requirements) | ASTM A 391/A (other)

| | | | |
|---|---|---|---|
| Date of receipt: | 2019-04-23 | Ordering party: | George Taylor & Co., UK |
| Producer/ Supplier: | Mining Tools and Equipment Factories Capital Group FASING Plc. | User: | - |
| | | Purchase Orde No.: | 76570 |
| Quantity supplied: | 100 m | Contract No.: | - |
| Production Order No.: | DE1/112/2019 | Purchase Ordedate: | 2019-04-12 |

| Item | Tested parameter or measured quantity | | Symbol | Unit of measurement | Required value | Measured value (Sample No. 1) |
|---|---|---|---|---|---|---|
| 1 | Nominal diameter of the round link | | $d_n$ | mm | 32±1,6 | 32,7 |
| 2 | Thickness of the flat link | | - | mm | - | - |
| 3 | Weld diameter | | $d_s$ | mm | max.37,0 | 33,2 |
| 4 | Weld width | | - | mm | - | - |
| 5 | Pitch | round link | p | mm | 96±2,9 | 96,1 |
| | | flat link | - | mm | - | - |
| 6 | Inside width | round link | $w_1$ | mm | min.41,6 | 46,4 |
| | | flat link | - | mm | - | - |
| 7 | Outside width | round link | $w_2$ | mm | max.118 | 111,2 |
| | | flat link | - | mm | - | - |
| 8 | Crown radius | | r | mm | - | - |
| 9 | Length of 11 links | | l | mm | 1056+5,3 | 1057,1 |
| 10 | Manufacture proof force | | MPF | kN | 804 | 804 |
| 11 | Breaking Force | | Fe/BF | kN | min.1290 | 1480 |
| 11a | ~~Working Force~~/Working Load Limit | | WF/WLL | kN/t | max.31,5 | 31,5 |
| 12 | Break place: L- leg; C - crown; W - weld | | | | | C |
| 13 | Elongation under test force | | Ep | % | - | - |
| 14 | Elongation at fracture | | Ek | % | min.20 | 38,5 |
| 15 | Deflection | | f | mm | 26 | 26 |
| 16 | Charpy-V-test | | KV | J | - | - |
| 17 | Hardness | | | UNIT * HRC, HBW, HV | - | - |
| 18 | Fatigue resistance | | Lower load $F_u$ : - [kN] Upper load $F_o$ : - [kN] Frequency of load changes N : - [Hz] | | | |
| | | | T/N | cycles | - | - |
| 19 | Break place: L- leg; C - crown; W - weld | | | | | - |

| Chemical analysis of the material acc. to DIN 17115 / ~~PN-92/H-93028~~ | Heat No.: | C | Si | Mn | P | S | Cr | Mo | Ni | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| | 221071 | 0,211 | 0,216 | 0,215 | 0,0154 | 0,0064 | 0,567 | 0,252 | 0,510 | 0,0281 |

Chemical composition in percentages by weight

Marking: H52-8 3/19

Remarks: Black painted ; 1194 kg

* delete as appropriate

| Quality Control | Department Manager | Management System Department |
|---|---|---|
| [redacted] | [redacted] | [redacted] |
| stamp and signature | | stamp and signature |

Image courtesy of Det Norske Veritas

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ACCOUNT NO 33014
CERTIFICATE NO 283213 G
PAGE 1

UK & EC DECLARATION OF CONFORMITY - All products are rated in metric tonnes.
These products are supplied in accordance with the Machinery Directive 2006/42/EC & Supply of Machinery (Safety) Regs 2008.

| DISTINGUISHING MARK | DESCRIPTION | QUANTITY | | ISSUE DATE | PROOF LOAD | W.L.L |
|---|---|---|---|---|---|---|
| H52-8 3/19 | G8C32 YOUR PO: 16998 GTO: 107585<br>GRADE 8 SHORT LINK CHAIN 32MM DIA - G8C32 - TO BS EN 818 -2 - SAFETY FACTOR 4 TO 1 - MIN ELONGATION 20% | 8 | M | 23/09/2019 | 804 Kn | 31.5 Tonne |

SIGNED ON BEHALF OF GEORGE TAYLOR & COMPANY BY: ____[redacted]____[redacted] Date: 08/02/2021

[illegible]

The certificate and/or declarations of conformity issued by the manufacturer are held on file at our offices and can be made available to an appropriate enforcing authority if they make such a request.
The items detailed have been designed and produced to be suitable for normal duties when correctly used by a competent person. Where an item is to be used in abnormal conditions or for arduous duties reference should be made to the manufacturer before such use. Failure to do so may absolve the manufacturer from his responsibility under Section 6 of the Health & Safety at Work etc Act 1974.

Image courtesy of Det Norske Veritas

# APPENDIX B
## Photo documentation

Image courtesy of Det Norske Veritas

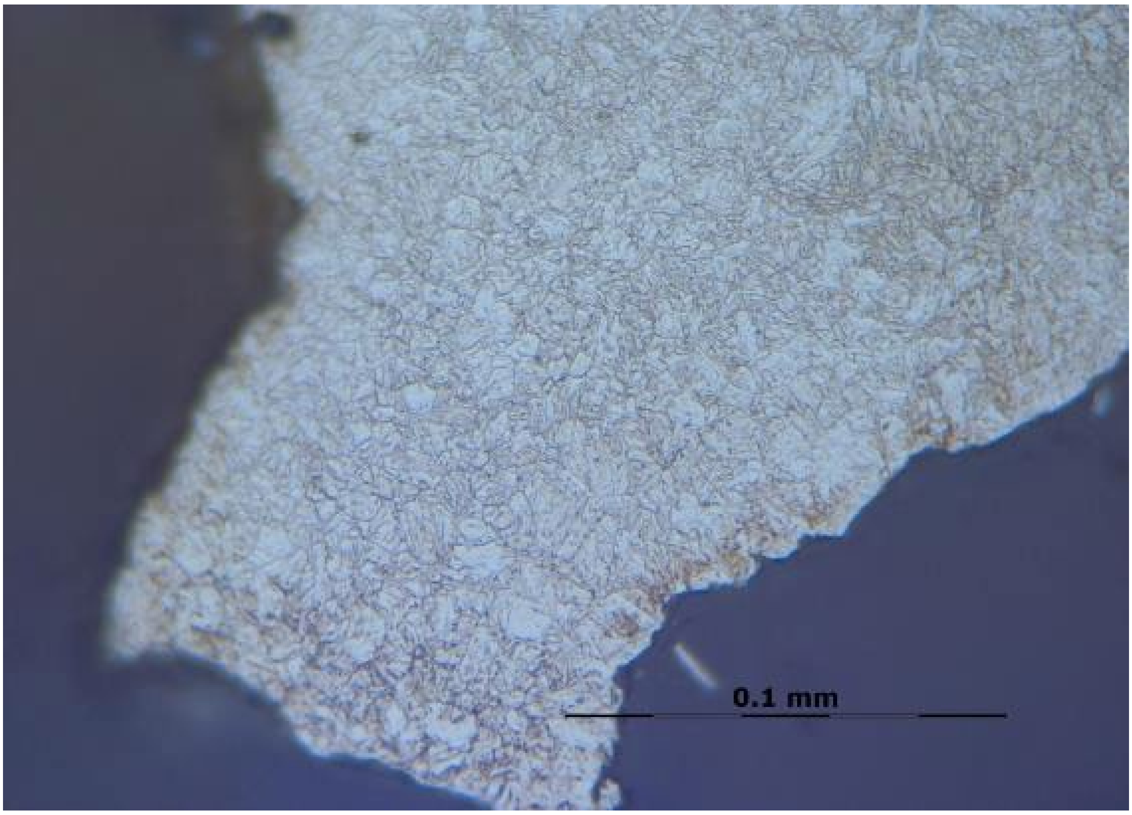



**Figure B-8-1 Cross section, link BJC/1-5: Quenched and tempered microstructure close to outer surface.**

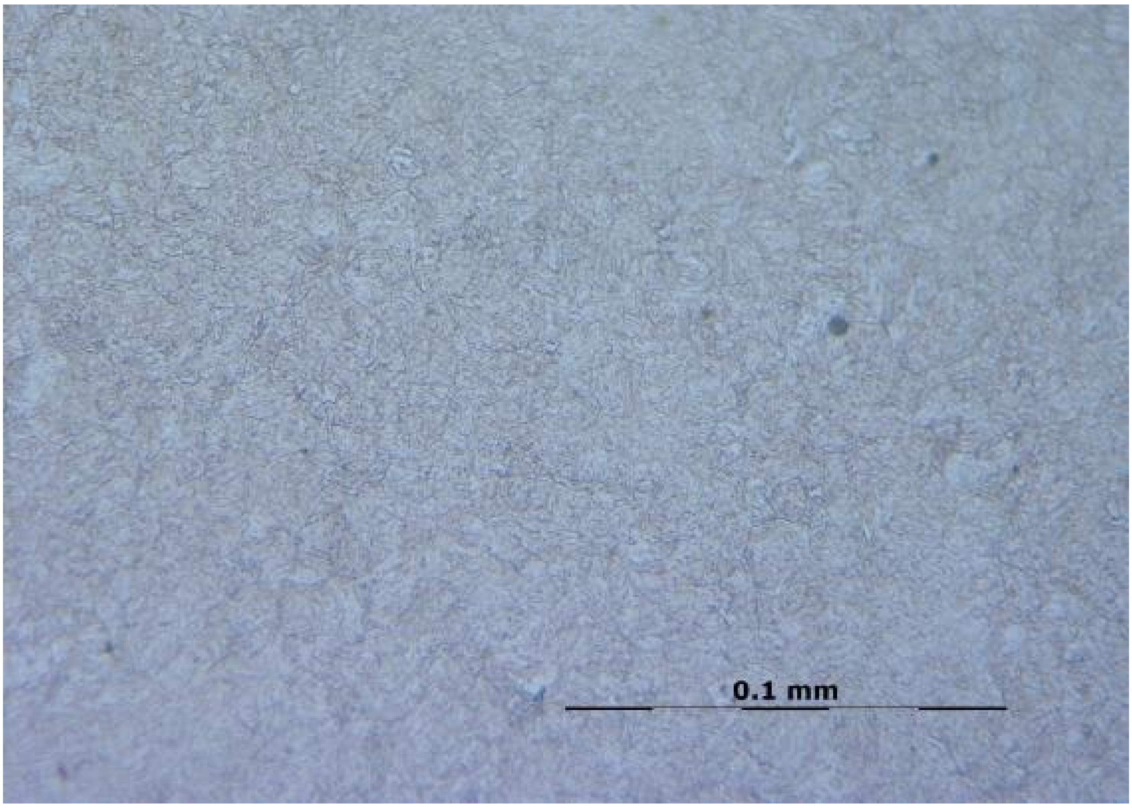



**Figure B-8-2 Cross section, link BJC/1-5: Quenched and tempered microstructure ca 10 mm from outer surface.**

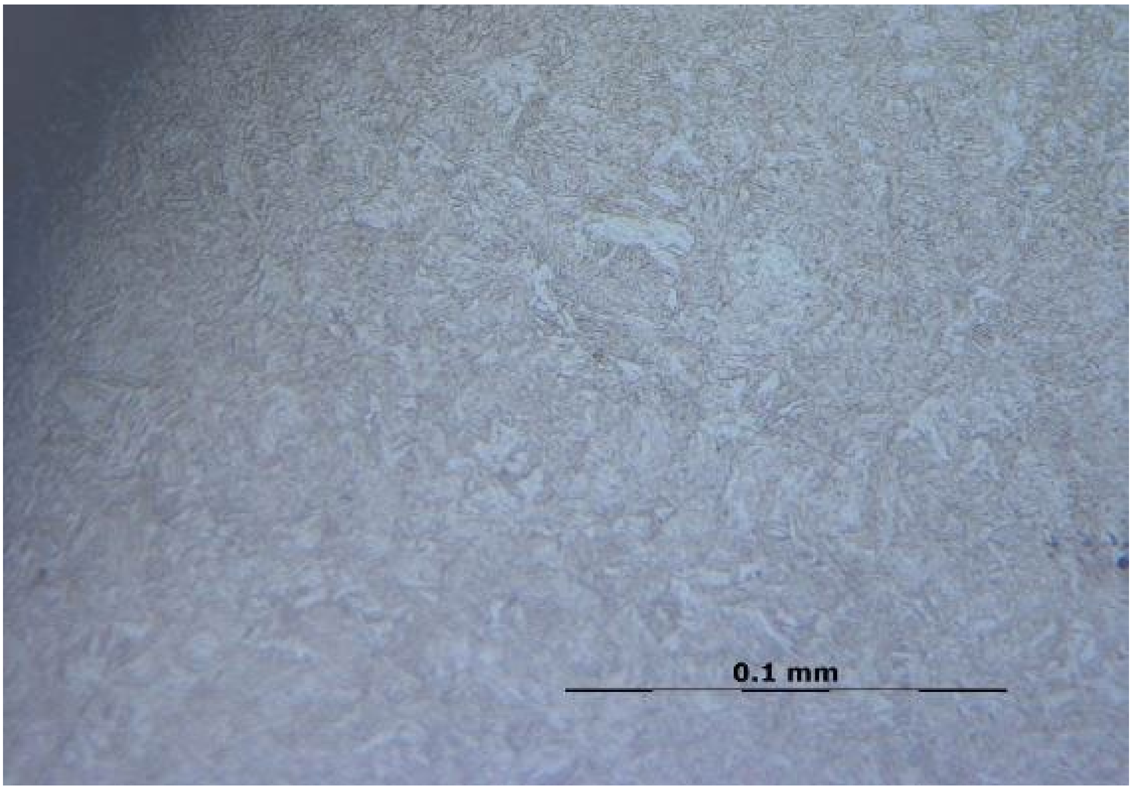



Figure B-8-3 Cross section, link BJC/2-9: Quenched and tempered microstructure close to outer surface.

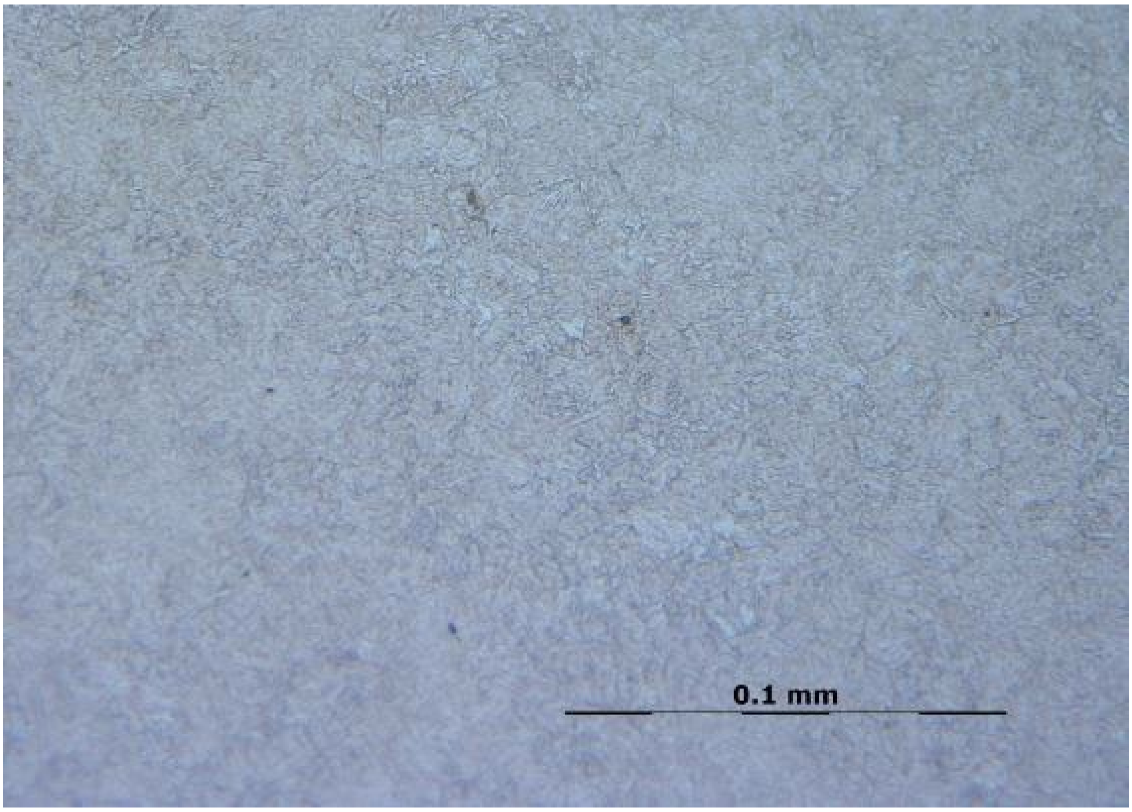



Figure B-8-4 Cross section, link BJC/2-9: Quenched and tempered microstructure ca 10 mm from outer surface.

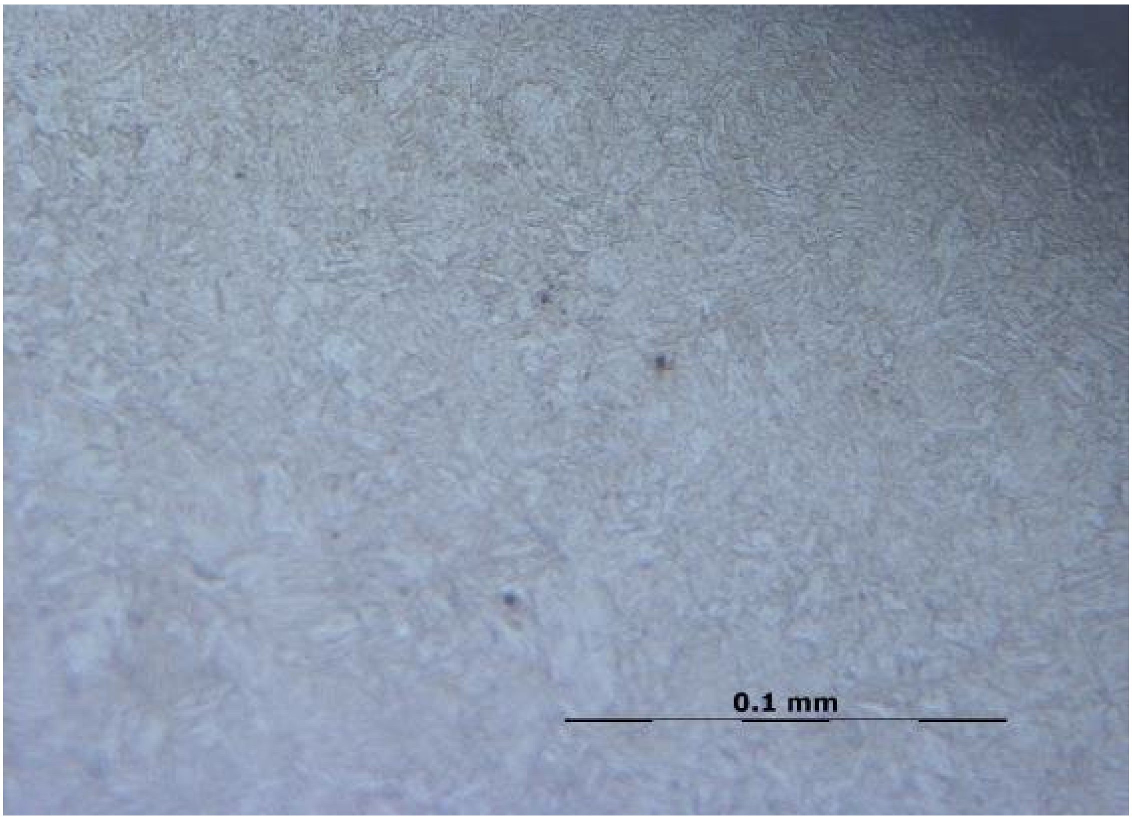



**Figure B-8-5 Cross section, link BJC/3-1: Quenched and tempered microstructure close to outer surface.**

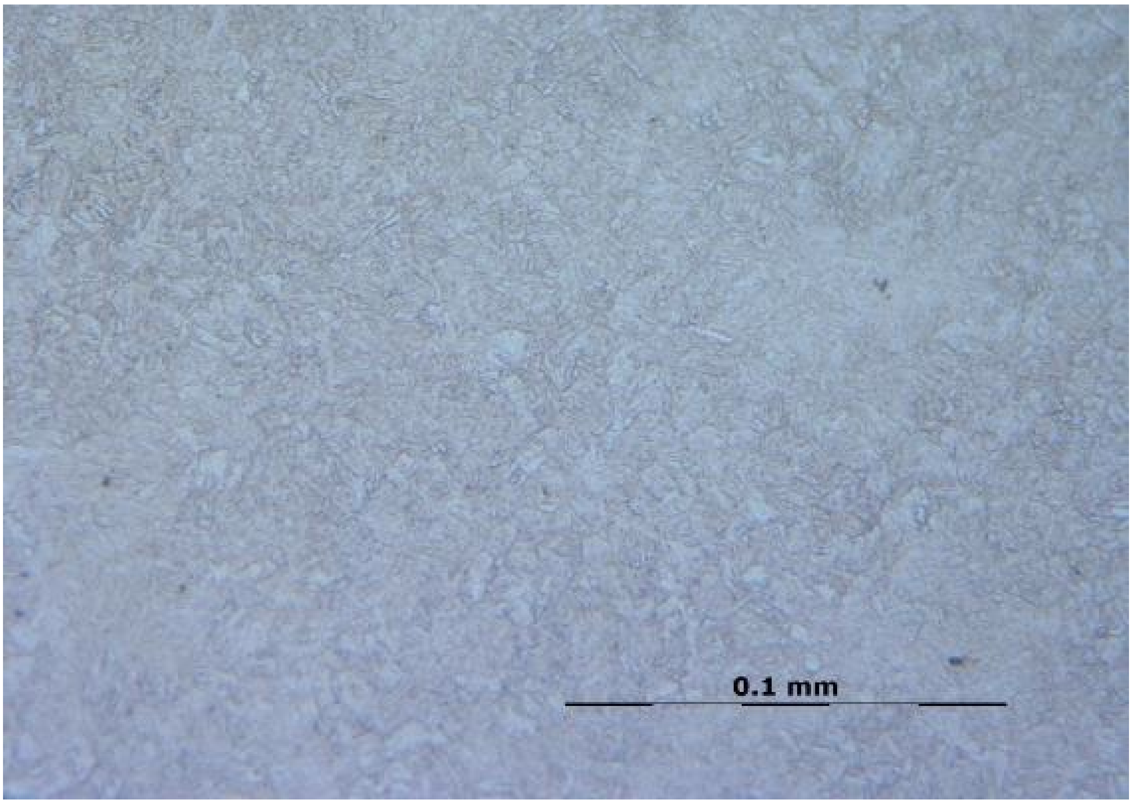



**Figure B-8-6 Cross section, link BJC/3-1: Quenched and tempered microstructure ca 10 mm from outer surface.**

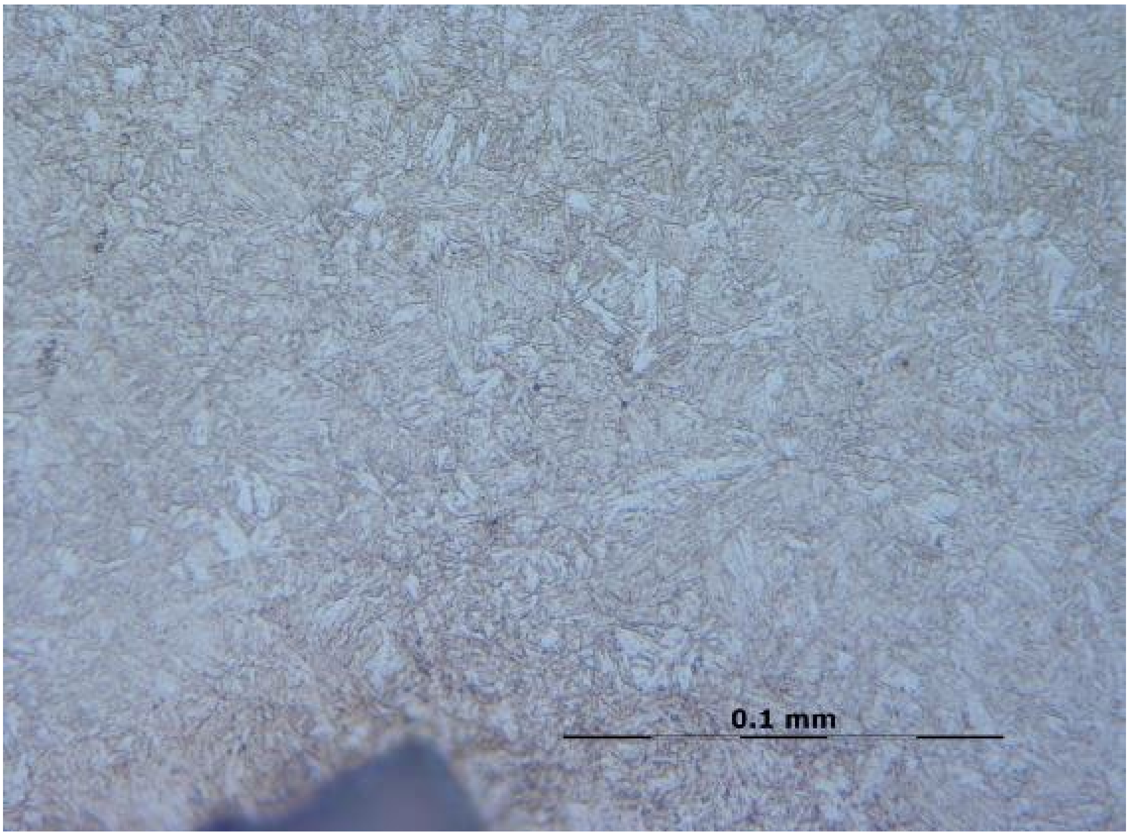



**Figure B-8-7 Cross section, link BJC/5-10: Quenched and tempered microstructure close to outer surface.**

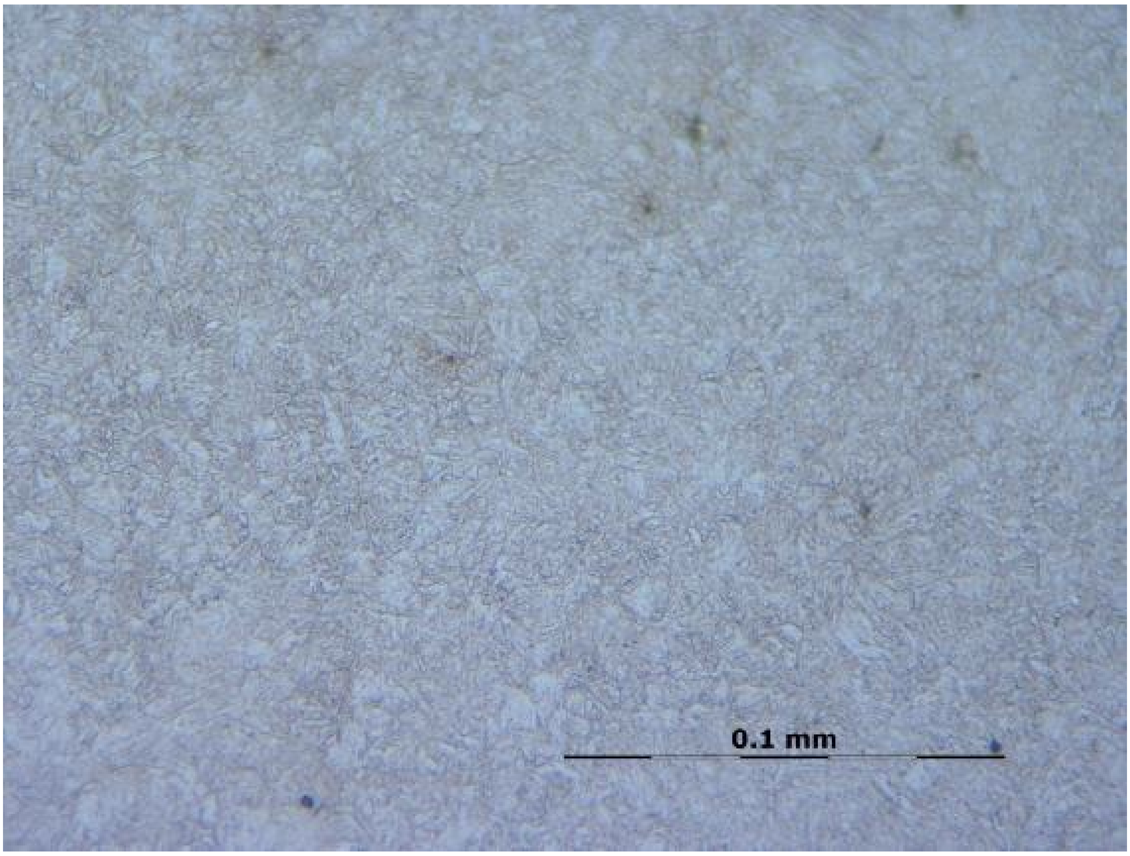



**Figure B-8-8 Cross section, link BJC/5-10: Quenched and tempered microstructure ca 10 mm from outer surface.**

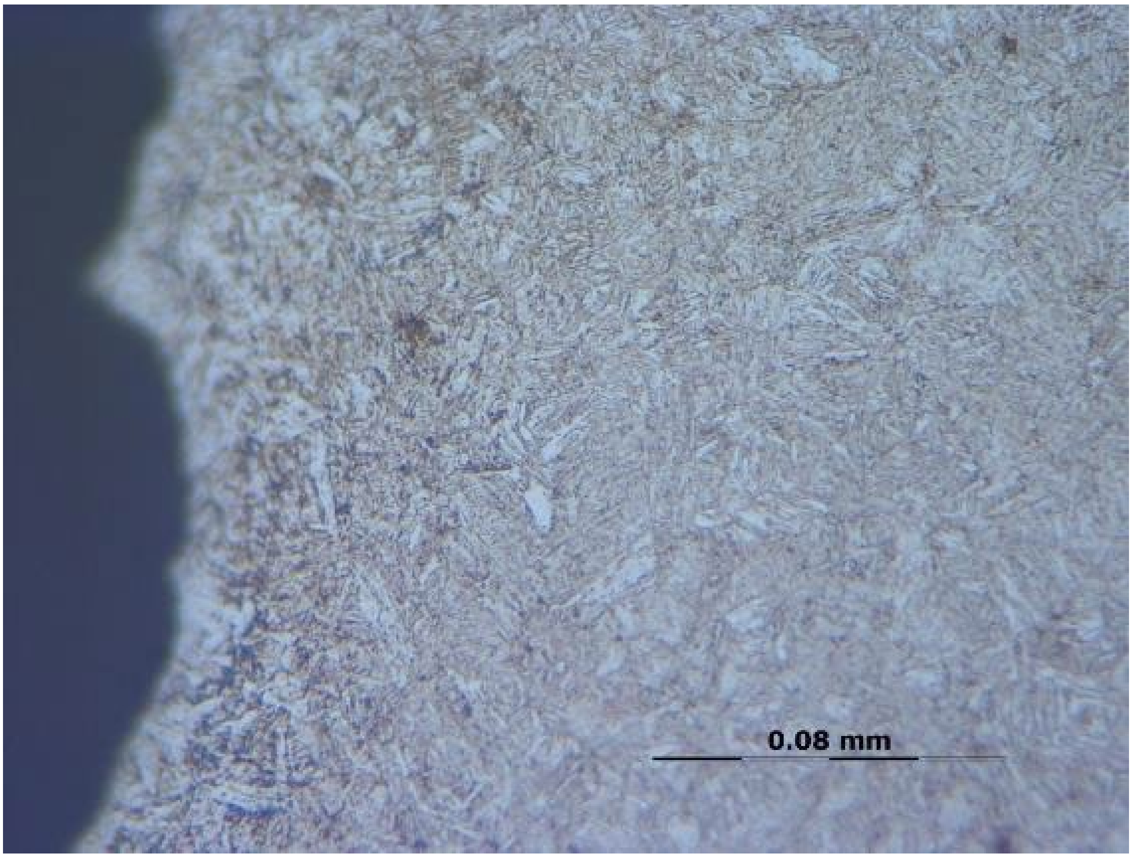


**Figure B-8-9 Cross section, fractured link: Quenched and tempered microstructure close to outer surface.**

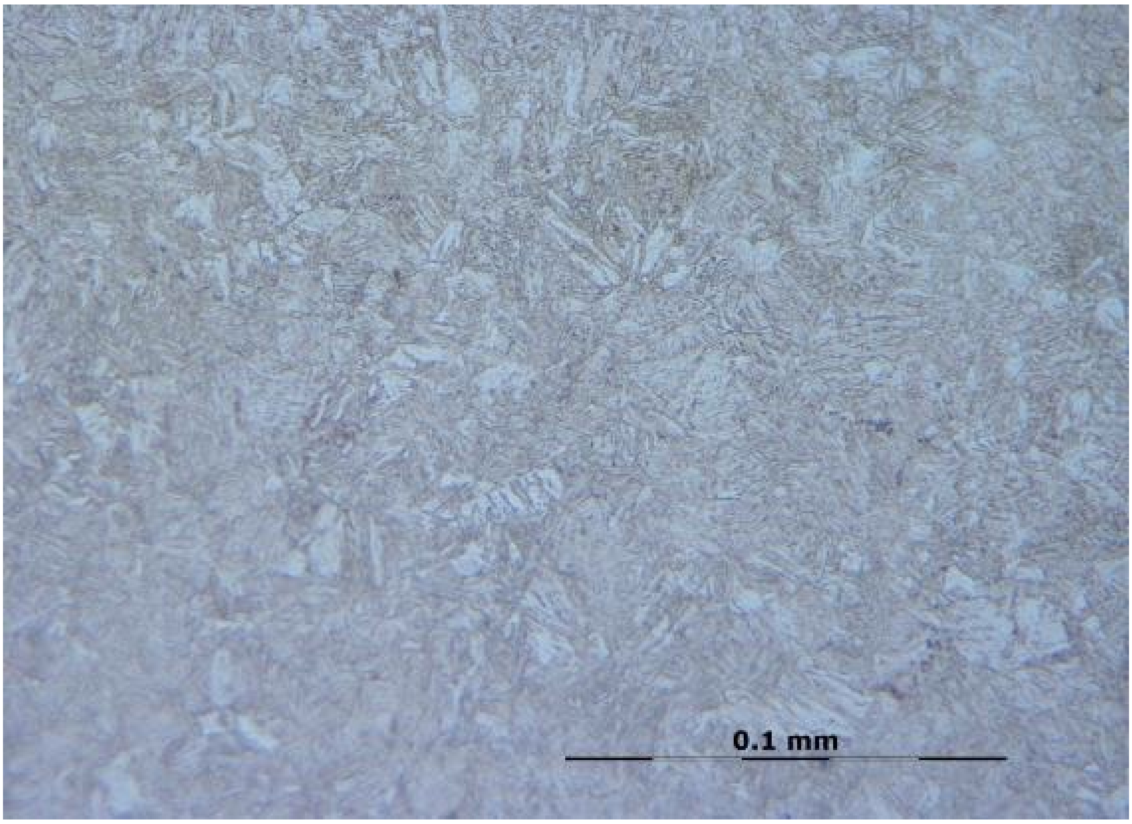



**Figure B-8-10 Cross section, fractured link: Quenched and tempered microstructure ca 10 mm from outer surface.**

Image courtesy of Det Norske Veritas

# APPENDIX C
## Reports from NDT

Image courtesy of Det Norske Veritas

# MAGNETPULVER RAPPORT
# MAGNETIC PARTICLE REPORT

OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| **1248239** | **0000210360/8029** | **1067442** | **0** |
| Kunde/Client: **Det Norske Veritas AS** | Antall vedlegg/Appendixes: **23** | Testdato/Date of test: **2021-08-11** | |
| Adresse/Address | Prosedyre/Procedure: **NS-EN ISO 17638** | Aksept standard/Accept std.: **---** | |
| Postaddresse / Postal address: **8608 MO I RANA** | Omfang/Extent: **100%** | Resultat/Result: **Ikke akseptert/Not accepted** | |
| Kontaktperson/Supervisor: [redacted] | Utstyr/Equipment: **UV-lamp, Yoke** | Materiale/Material: **C/S** | |

| Undersøkelsested/Test site: **DNV, Bergen** | Tegning nr./Drawing No.: **---** |
|---|---|
| Inspeksjon av/Inspection of: **Chain & Chainlink** | |

| Overflate/Surface | Sveisemetode/Welding proc. | Fugetype/Joint | Varmebehandlet/Heat treated |
|---|---|---|---|
| **Forged, acidwashed.** | **---** | **---** | **---** |
| Feltstyrke/Field strength: **2,3-4,5kAm** | Feltindikator/Field indicator: **Castrolstrips** | Kontrastmaling/Contrast paint: **---** | Magnetisert for/Magnatized for: **Lat/Long.** |

| Spole/Coil: ☐ | Yoke: ☑ | Annen/Other: ☐ |
|---|---|---|
| Type: | Type: **Magnaflux Y6** | |
| | S.Max: **100 mm** | |
| Strøm/Current: | Strøm/Current: **AC** | |
| Kontrollmiddel/Examination medium | Kontrollmiddel/Examination medium | |
| Våt/Wet: ☑ Tørr/Dry: ☐ | Svart/Black: ☐ | Fluoriserende/Fluorescent: ☑ |

Anmerkninger/Comments

**Extent of inspection:**

**-------------------------**

**100% Fluorescent magnetic particle inspection of 4 length of chain & 1 fractured link.**

Resultat/Results

**Part BJC/1: Lenght of 5 links. Portside.**
**Marked with pink strip at one end. Links numbered from pink strip.**

**Link no.1: 5 linar indicatins.**

-------------------------

**Part BJC/2: Length of 9 links. Unused**
**Marked with blue strip at one end.**
**Coated, thicnes of coating was specified by costumer to ca 50my.**

**No indication.**

**-------------------------**

**Part BJC/3: Lenght 10 links. Starbordside.**
**Marked with green strip at one end. Links numbered from green strip.**

**Link no.2: 3 linar indications.**
**Link no.3: 2 linar indications.**
**Link no.4: 5 linar indications.**
**Link no.5: 1 linar indication.**
**Link no.6: 1 linar indication.**
**Link no.7: 1 linar indication.**
**Link no.10: 2 linar indications.**

| Dato/Date | Operatør/Operator | Dato/Date | Rapport godkjent/Report approved |
|---|---|---|---|
| 2021-08-12 | [redacted] | 2021-08-16 | [redacted] |

Oceaneering Asset Integrity AS - Sandslimarka 61-63, N-5254 Sandsli - Tel: + 47 56 31 60 00, NO 965 591 095 MvA

www.oceaneering.com

Image courtesy of [Det Norske Veritas]

DNV

MAGNETPULVER RAPPORT
MAGNETIC PARTICLE REPORT

OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| 1248239 | 0000210360/8029 | 1067442 | 0 |

--------------------------

**Part BJC/4: Part of fractured link portside.**

**No Indication.**

--------------------------

**Part BJC/5: Lenght 4 links. Portside.**
**Marked with orange strip at one end. Links numbered from orange strip.**

**Link no.2: 1 small indication.**

| Dato/Date | Operatør/Operator | Dato/Date | Rapport godkjent/Report approved |
|---|---|---|---|
| 2021-08-12 | [redacted] | 2021-08-16 | [redacted] |

Oceaneering Asset Integrity AS - Sandslimarka 61-63, N-5254 Sandsli - Tel: + 47 56 31 60 00, NO 965 591 095 MVA

www.oceaneering.com

Image courtesy of Det Norske Veritas

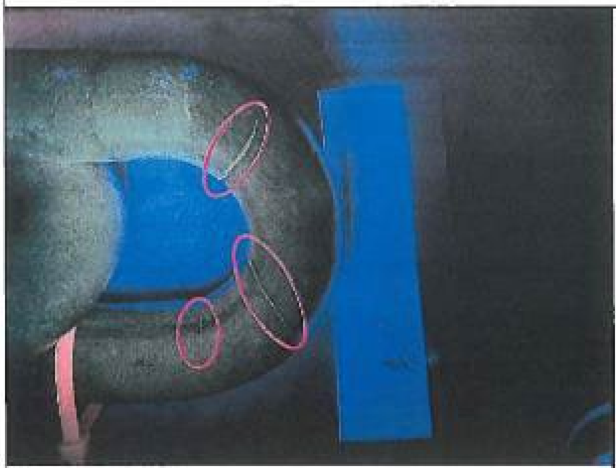
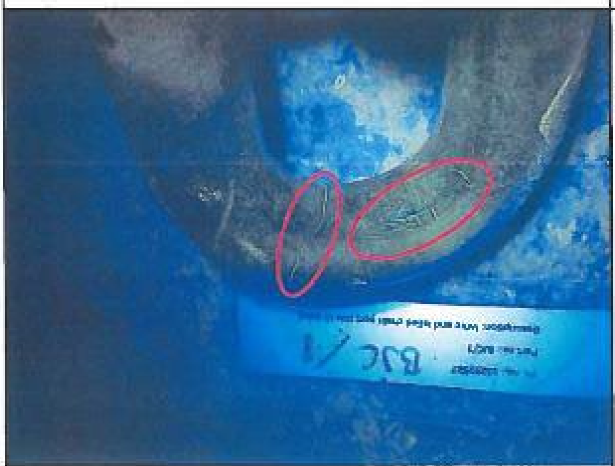
DNV

# FOTOVEDLEGG
# IMAGE ATTACHMENTS

OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| **1248239** | **0000210360/8029** | **1067442** | **0** |

**Bilder / Images**

| | |
|---|---|
|  | Filnavn / Filename: 3 5AC5974B-ED62-4004-9D9F-5C391CF59676.jpg<br><br>Beskrivelse / Description:<br>BJC-1 Link no1 |
|  | Filnavn / Filename: 9 02D1922B-48CD-49E9-8D2A-550E65C16620.jpg<br><br>Beskrivelse / Description:<br>BJC-1 Link no1 |

DNV

**FOTOVEDLEGG**
**IMAGE ATTACHMENTS**

OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| **1248239** | **0000210360/8029** | **1067442** | **0** |

Filnavn / Filename: 1 839A5881-C830-43C0-8993-FD0C0EA207D6.jpg

Beskrivelse / Description:
BJC-1 Link no1

Filnavn / Filename: 15 1DC6FD9B-BA7B-4814-9469-BBB432D1C1AD.jpg

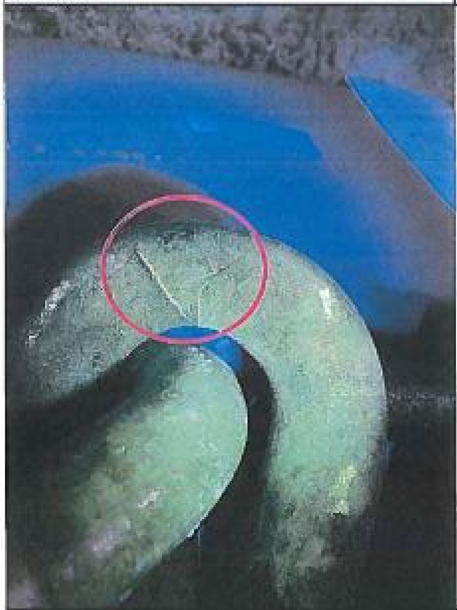
Beskrivelse / Description:
BJC-3 Link no2

DNV

## FOTOVEDLEGG
## IMAGE ATTACHMENTS

OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| **1248239** | **0000210360/8029** | **1067442** | **0** |



Filnavn / Filename: 16 13C06F29-B0FF-4166-BF64-3DE2AB82B7CB.jpg

Beskrivelse / Description:
BJC-3 Link no2

Filnavn / Filename: 14 F8A74DD8-480F-46D4-B521-566EDCC74018.jpg

Beskrivelse / Description:
BJC-3 Link no2

Image courtesy of Det Norske Veritas

# FOTOVEDLEGG
# IMAGE ATTACHMENTS

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| 1248239 | 0000210360/8029 | 1067442 | 0 |

Filnavn / Filename: 17 273FEBB0-5DCA-4288-B672-5AD947BEFF06.jpg

Beskrivelse / Description:
BJC-3 Link no3

Filnavn / Filename: 18 05EFCF59-B937-42E7-BC1E-327CB4754698.jpg

Beskrivelse / Description:
BJC-3 Link no3

Image courtesy of Det Norske Veritas

DNV

**FOTOVEDLEGG**
**IMAGE ATTACHMENTS**

OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| **1248239** | **0000210360/8029** | **1067442** | **0** |

Filnavn / Filename: 19 7471B801-7416-4A9D-9FED-2DEDD15A705C.jpg

Beskrivelse / Description:
BJC-3 Link no3

Filnavn / Filename: 20 C0E03C22-F4A2-44EE-8799-585254C1EE88.jpg

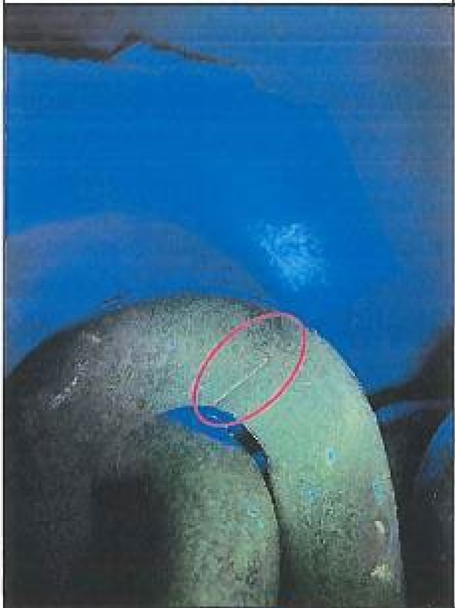
Beskrivelse / Description:
BJC-3 Link no4

DNV

# FOTOVEDLEGG
# IMAGE ATTACHMENTS

OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| 1248239 | 0000210360/8029 | 1067442 | 0 |



Filnavn / Filename: 21 B681D45C-6916-4EA1-8192-FE415FF3636F.jpg

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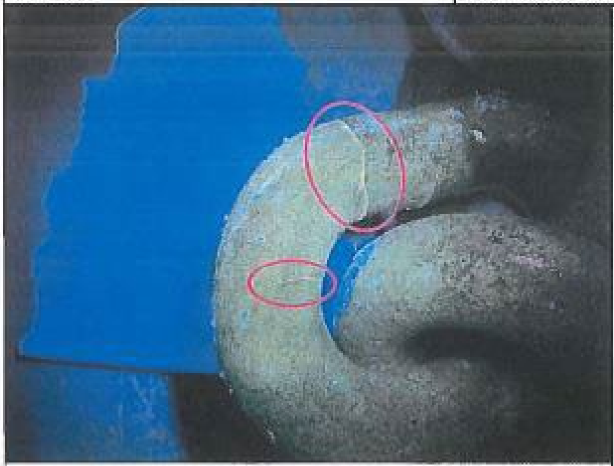
BJC-3 Link no4

Filnavn / Filename: 22 94B70FCC-D564-488A-AF7A-3BEB9AD516D6.jpg

Beskrivelse / Description:
BJC-3 Link no4

# FOTOVEDLEGG
# IMAGE ATTACHMENTS

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| **1248239** | **0000210360/8029** | **1067442** | **0** |



Filnavn / Filename: 23 FD30D751-CB2C-4E04-BC53-DC434C3C7EB6.jpg

Beskrivelse / Description:
BJC-3 Link no4

Filnavn / Filename: 24 49095FD3-87F9-41A3-98E8-100A638FB4C0.jpg

Beskrivelse / Description:
BJC-3 Link no4

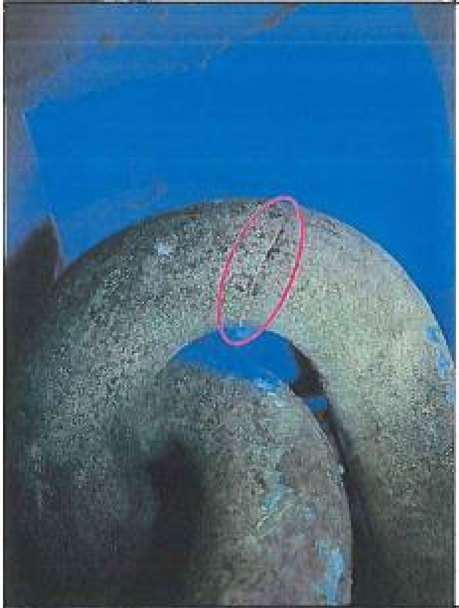
Image courtesy of Det Norske Veritas

DNV

# FOTOVEDLEGG
# IMAGE ATTACHMENTS

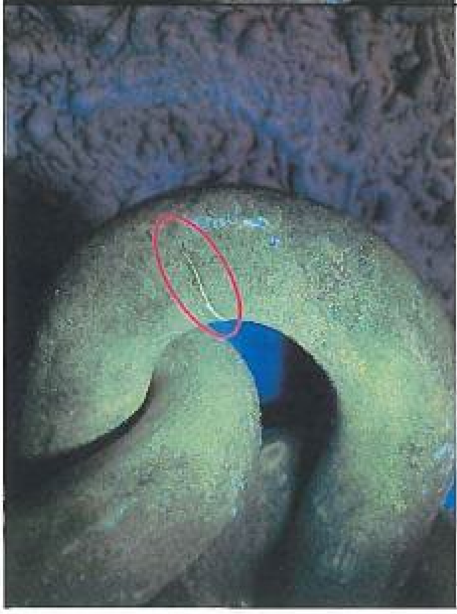
OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| **1248239** | **0000210360/8029** | **1067442** | **0** |



Filnavn / Filename: 25 2D791FE4-0E92-47B2-9DC8-1E7C2305AF4F.jpg

Beskrivelse / Description:
BJC-3 Link no5



Filnavn / Filename: 26 8/54B42F-86FD-4242-A3ED-25736039CFAF.jpg

Beskrivelse / Description:
BJC-3 Link no5

DNV

# FOTOVEDLEGG
# IMAGE ATTACHMENTS

OCEANEERING

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| 1248239 | 0000210360/8029 | 1067442 | 0 |

Filnavn / Filename: 27 6CB94768-9D08-4153-9A0B-FA27E7583AF6.jpg

Beskrivelse / Description:
BJC-3 Link no5

Filnavn / Filename: 28 B1631BD5-8266-401B-B41E-8A0490EB40C2.jpg

Beskrivelse / Description:
BJC-3 Link no6

Image courtesy of Det Norske Veritas

DNV

**FOTOVEDLEGG**
**IMAGE ATTACHMENTS**

OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| **1248239** | **0000210360/8029** | **1067442** | **0** |

Filnavn / Filename: 30 2A3E8665-E371-4A31-9D9F-C79A6E276472.jpg

Beskrivelse / Description:
BJC-3 Link no7

Filnavn / Filename: 32 2934BEEF-78B8-470E-B3C6-90D4BD3FD831.jpg

Beskrivelse / Description:
BJC-3 Link no10

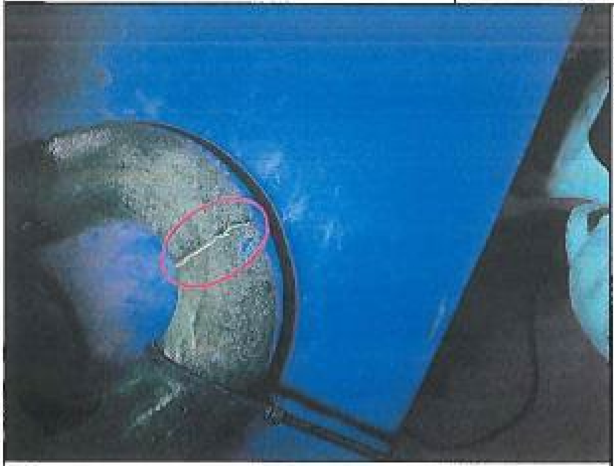
Image courtesy of Det Norske Veritas

DNV

# FOTOVEDLEGG
# IMAGE ATTACHMENTS

OCEANEERING

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| 1248239 | 0000210360/8029 | 1067442 | 0 |



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Beskrivelse / Description:
BJC-3 Link no10

Filnavn / Filename: 4 BD0F6BD1-639A-4805-BEE5-D05F3A96A59B.jpg

Beskrivelse / Description:
BJC-5 Link no2

Image courtesy of Det Norske Veritas

DNV

# EN ISO 9712

NORDTEST

## NDT LEVEL 2 CERTIFICATE

### Test method: Magnetic Particle Testing

[redacted]

Ruskeneshauen 9, 5251 Søreidgrend, Norway

Date of birth:
1963-05-27

Number: 8109-N2-M

| | |
|---|---|
| Date of first issue: | 2013-09-13 |
| Date of renewal: | 2018-09-13 |
| Date of expiry: | 2023-09-13 |

[redacted]

2018.09.05

[redacted]

Signature holder of certificate

Fulfills the requirements in Directive 2014/68/EU Pressure equipment

The certificate holder fulfills all requirements of EN ISO 9712 and NORDTEST DOC GEN 010, edition 6.

| | |
|---|---|
| **Sector:** | IMU Multisector (All industrial sectors) |
| **Supplemental sector:** | Non |
| **Sector limitation:** | No limitations |

**Initial certification body:**
FORCE Norway

FORCE TECHNOLOGY

This certificate is a copy
2018.09.05

Force Technology CB NORWAY

FORCE Technology Norway

NORSK AKKREDITERING PERS 002

The certificate is valid only with the operating authorization which is based on visual acuity and proof of satisfactory work with the actual NDT method, without interruptions totally not more than 1 year, for the whole validity period. The documentation file of the certificate holder shall also include complaints within the scope of the certification competence. The operating authorization shall be renewed annually.

Operating authorization by employer:

OCEANEERING

**Oceaneering Asset Integrity AS**
Sandslimarka 62 -63, 5254 SANDSLI, Norway

NTO no. N-007

| | | |
|---|---|---|
| 2018.09.13 | 2019.09.13 | 2020.09.13 |
| [redacted] | [redacted] | [redacted] |
| Authorised signature/Employer: first time issue | Authorised signature/Employer: renewed 1st year | Authorised signature/Employer: renewed 2nd year |
| 2021.09.13 | 2022.09.13 | 2023.09.13 |
| Authorised signature/Employer: renewed 3rd year | Authorised signature/Employer: renewed 4th year | Authorised signature/Employer: renewed 5th year |

DNV

# MAGNETPULVER RAPPORT
# MAGNETIC PARTICLE REPORT

OCEANEERING®

| | | | |
|---|---|---|---|
| Kunde PO/Customer PO<br>**1248239** | Vårt prosjektnr./Our project no.<br>**0000210360/8029** | Rapportnr / Report no<br>**1067829** | Rev<br>**0** |
| Kunde/Client<br>**Det Norske Veritas AS** | Antall vedlegg/Appendixes<br>**4** | Testdato/Date of test<br>**2021-08-12** | |
| Adresse/Address | Prosedyre/Procedure<br>**NS-EN ISO 17638** | Aksept standard/Accept std.<br>**All indications reported** | |
| Postaddresse / Postal address<br>**8608 MO I RANA** | Omfang/Extent<br>**100%** | | |
| Kontaktperson/Supervisor<br>[redacted] | Utstyr/Equipment<br>**UV-lamp, Yoke** | Materiale/Material<br>**CS** | |

| | |
|---|---|
| Undersøkelsested/Test site<br>**Ågotnes** | Tegning nr./Drawing No.<br>--- |
| Inspeksjon av/Inspection of<br>**2 numbers of Derrec Heads**<br>**1. MPH/CM/SB/1:**<br>**2. MPH/CM/PORT/3** | |

| | | | |
|---|---|---|---|
| Overflate/Surface<br>**Sandblasted** | Sveisemetode/Welding proc.<br>--- | Fugetype/Joint<br>--- | Varmebehandlet/Heat treated<br>--- |
| Feltstyrke/Field strength<br>**2,3-4,5kAm** | Feltindikator/Field indicator<br>**Castrolstrips** | Kontrastmaling/Contrast paint<br>--- | Magnetisert for/Magnatized for<br>**Lat/Long** |

| | | |
|---|---|---|
| Spole/Coil: ☐<br>Type:<br>Strøm/Current: | Yoke: ☑<br>Type: **Magnaflux Y6**<br>S.Max: **150 mm**<br>Strøm/Current: **AC** | Annen/Other: ☐ |
| Kontrollmiddel/Examination medium<br>Våt/Wet: ☑ Tørr/Dry: ☐ | Kontrollmiddel/Examination medium<br>Svart/Black: ☐ Fluoriserende/Fluorescent: ☑ | |

Anmerkninger/Comments

**Extent of inspection:**

------------------------

**100% Fluorescent magnetic particle inspection of 2 numbers of Derrec Heads.**

**Marked:**
- **MPH/CM/SB/1**
- **MPH/CM/PORT/3**

Resultat/Results

**Derrec Head MPH/CM/SB/1:**

**No indication detected.**

--------------------

**Derrec Head MPH/CM/PORT/3**

**Some small indications locaded 3 places.**

**See added pictures.**

| | |
|---|---|
| Dato/Date 2021-08-17 | Operatør/Operator [redacted] |
| Dato/Date 2021-08-17 | Rapport godkjent/Report approved [redacted] |

Oceaneering Asset Integrity AS Sandslimarka 61 63, N 5254 Sandsli Tel: +47 56 31 60 00, NO 965 591 095 MVA

www.oceaneering.com

DNV

**FOTOVEDLEGG**
**IMAGE ATTACHMENTS**

OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| **1248239** | **0000210360/8029** | **1067829** | **0** |

**Bilder /Images**

Filnavn / Filename: PORT_3.jpeg

Beskrivelse / Description:
PORT_3. Indications 3 places

Filnavn / Filename: Head1.jpg

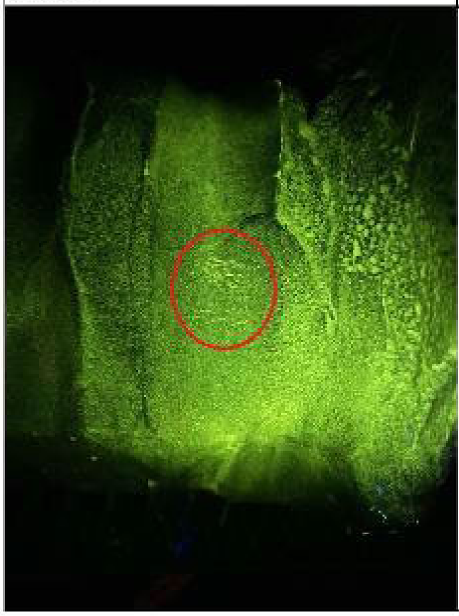
Beskrivelse / Description:
Indication 1&2

DNV

# FOTOVEDLEGG
# IMAGE ATTACHMENTS

OCEANEERING®

| Kunde PO/Customer PO | Vårt prosjektnr./Our project no. | Rapportnr / Report no | Rev |
|---|---|---|---|
| **1248239** | **0000210360/8029** | **1067829** | **0** |



Filnavn / Filename: Head2.jpg

Beskrivelse / Description:
Indication 3

# EN ISO 9712

NORDTEST

## NDT LEVEL 2 CERTIFICATE

**Test method: Magnetic Particle Testing**

Number: 8109-N2-M

[redacted]

Ruskeneshauen 9, 5251 Søreidgrend, Norway

Date of birth:
1963-05-27

| | |
|---|---|
| Date of first issue: | 2013-09-13 |
| Date of renewal: | 2018-09-13 |
| Date of expiry: | 2023-09-13 |

[redacted]

2018.09.05

[redacted]

Signature holder of certificate

Fulfills the requirements in Directive 2014/68/EU Pressure equipment

The certificate holder fulfills all requirements of EN ISO 9712 and NORDTEST DOC GEN 010, edition 6.

| | |
|---|---|
| Sector: | IMU Multisector (All industrial sectors) |
| Supplemental sector: | Non |
| Sector limitation: | No limitations |

**Initial certification body:**
FORCE Norway

FORCE TECHNOLOGY

This certificate is a copy
2018.09.05

Force Technology CB NORWAY

FORCE Technology Norway

NORSK AKKREDITERING PERS 002

The certificate is valid only with the operating authorization which is based on visual acuity and proof of satisfactory work with the actual NDT method, without interruptions totally not more than 1 year, for the whole validity period. The documentation file of the certificate holder shall also include complaints within the scope of the certification competence. The operating authorization shall be renewed annually.

**Operating authorization by employer:**

OCEANEERING

Oceaneering Asset Integrity AS
Sandslimarka 62-63, 5254 SANDSLI, Norway

NTO no. N-007

| 2018.09.13 | 2019.09.13 | 2020.09.13 |
|---|---|---|
| [redacted] | [redacted] | [redacted] |
| [illegible] | [illegible] | [illegible] |

| 2021.09.13 | 2022.09.13 | 2023.09.13 |
|---|---|---|
| | | |
| [illegible] | [illegible] | [illegible] |

Image courtesy of Det Norske Veritas

# APPENDIX D
## Reports from chemical analyses

DNV

# D-LAB

DEGERFORS LABORATORIUM AB



## Provningsresultat / Test Results:

SWEDAC ACKREDITERING

| Beställare / Client | Referens / Reference | Ordernr / Orderno |
|---|---|---|
| DNV GL AS | [redacted] | DL-70664 |

| Adress / Address |
|---|
| P.O. Box 300,Org. ID No: 945748931MVA, NO-1322 HÖVIK |

| Er beställning / Your order No | Ankomstdag / Sample Registration Date | Utskriftsdatum / Date of issue | DL ID |
|---|---|---|---|
| 10299927 | 2021-09-10 | 2021-09-13 | 695979 |

Provbeteckning / Sample identity

1-5

Noteringar / Notes

| Resultat/ Results | | Mätosäkerhet/ Uncertainty of measurement | Ackrediterat mätområde Accredited range of measurement | Standard metod Standard method | Dlab metod/ Dlab method |
|---|---|---|---|---|---|
| C | 0.230 % | 0.009 % | 0.0020 - 5.0 % | ASTM E 1019-18 | 5.4-058M |
| Si | 0.23 % | 0.007 % | 0.01 - 4 % | ASTM E 572-13 | 5.4-054M |
| Mn | 1.25 % | 0.009 % | 0.01 - 15 % | ASTM E 572-13 | 5.4-054M |
| P | 0.015 % | 0.002 % | 0.002 - 0.05 % | ASTM E 1086-14 | 5.4-057M |
| S | 0.005 % | 0.001 % | 0.0010 - 0.35 % | ASTM E 1019-18 | 5.4-058M |
| Cr | 0.58 % | 0.002 % | 0.01 - 30 % | ASTM E 572-13 | 5.4-054M |
| Ni | 0.50 % | 0.004 % | 0.01 - 40 % | ASTM E 572-13 | 5.4-054M |
| Mo | 0.25 % | 0.007 % | 0.01 - 8 % | ASTM E 572-13 | 5.4-054M |
| Ti | 0.003 % | 0.002 % | 0.003 - 2 % | ASTM E 572-13 | 5.4-054M |
| Nb | <0.005 % | * | 0.005 - 2 % | ASTM E 572-13 | 5.4-054M |
| Cu | 0.14 % | 0.002 % | 0.010 - 4 % | ASTM E 572-13 | 5.4-054M |
| Co | <0.005 % | * | 0.005 - 16 % | ASTM E 572-13 | 5.4-054M |
| N | 0.007 % | 0.001 % | 0.0002 - 0.50 % | ASTM E 1019-18 | 5.4-061M |
| Sn | 0.009 % | 0.0005 % | 0.002 - 0.1 % | ASTM E 572-13 | 5.4-054M |
| W | <0.01 % | * | 0.01 - 17 % | ASTM E 572-13 | 5.4-054M |
| V | 0.064 % | 0.001 % | 0.005 - 4 % | ASTM E 572-13 | 5.4-054M |
| Al | 0.026 % | 0.005 % | 0.01 - 0.3 % | ASTM E 1086-14 | 5.4-057M |
| Ta | <0.002 % | * | | | |
| Ca | 0.0009 % | * | | | |
| B | 0.0003 % | 0.00006 % | 0.0002 - 0.005 % | ASTM E 1086-14 | 5.4-057M |
| As | 0.004 % | 0.0005 % | 0.001 - 0.030 % | ASTM E 1086-14 | 5.4-057M |
| Fe | 96.66 % | * | | | |

* Ej ackrediterad analys / Not accredited analysis

The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor of k=2, providing a level of confidence of approximately 95%.



Note. The results are only valid for the sample that has been delivered to the laboratory.

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BIC/SWIFT: SWEDSESS

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D-LAB

DEGERFORS LABORATORIUM AB

2 1 5 ?

## Provningsresultat / Test Results:

Ordernr / Ordernr

DL-70664

| Beställare / Client | Referens / Reference |
|---|---|
| DNV GL AS | [redacted] |

Adress / Address

P.O. Box 300,Org. ID No: 945748931MVA, NO-1322 HÖVIK

| Er beställning / Your order No | Ankomstdag / Sample Registration Date | Utskriftsdatum / Date of issue | DL ID |
|---|---|---|---|
| 10299927 | 2021-09-10 | 2021-09-13 | 695980 |

Provbeteckning / Sample identity

2-9

Noteringar / Notes

| Resultat/ Results | | Mätosäkerhet/ Uncertainty of measurement | Ackrediterat mätområde Accredited range of measurement | Standard metod Standard method | Dlab metod/ Dlab method |
|---|---|---|---|---|---|
| C | 0.227 % | 0.009 % | 0.0020 - 5.0 % | ASTM E 1019-18 | 5.4-058M |
| Si | 0.23 % | 0.007 % | 0.01 - 4 % | ASTM E 572-13 | 5.4-054M |
| Mn | 1.26 % | 0.009 % | 0.01 - 15 % | ASTM E 572-13 | 5.4-054M |
| P | 0.015 % | 0.002 % | 0.002 - 0.05 % | ASTM E 1086-14 | 5.4-057M |
| S | 0.005 % | 0.001 % | 0.0010 - 0.35 % | ASTM E 1019-18 | 5.4-058M |
| Cr | 0.58 % | 0.002 % | 0.01 - 30 % | ASTM E 572-13 | 5.4-054M |
| Ni | 0.49 % | 0.004 % | 0.01 - 40 % | ASTM E 572-13 | 5.4-054M |
| Mo | 0.25 % | 0.007 % | 0.01 - 8 % | ASTM E 572-13 | 5.4-054M |
| Ti | 0.003 % | 0.002 % | 0.003 - 2 % | ASTM E 572-13 | 5.4-054M |
| Nb | <0.005 % | * | 0.005 - 2 % | ASTM E 572-13 | 5.4-054M |
| Cu | 0.14 % | 0.002 % | 0.010 - 4 % | ASTM E 572-13 | 5.4-054M |
| Co | <0.005 % | * | 0.005 - 16 % | ASTM E 572-13 | 5.4-054M |
| N | 0.008 % | 0.001 % | 0.0002 - 0.50 % | ASTM E 1019-18 | 5.4-061M |
| Sn | 0.008 % | 0.0005 % | 0.002 - 0.1 % | ASTM E 572-13 | 5.4-054M |
| W | <0.01 % | * | 0.01 - 17 % | ASTM E 572-13 | 5.4-054M |
| V | 0.061 % | 0.001 % | 0.005 - 4 % | ASTM E 572-13 | 5.4-054M |
| Al | 0.025 % | 0.005 % | 0.01 - 0.3 % | ASTM E 1086-14 | 5.4-057M |
| Ta | <0.002 % | * | | | |
| Ca | 0.0009 % | * | | | |
| B | 0.0003 % | 0.00006 % | 0.0002 - 0.005 % | ASTM E 1086-14 | 5.4-057M |
| As | 0.004 % | 0.0005 % | 0.001 - 0.030 % | ASTM E 1086-14 | 5.4-057M |
| Fe | 96.67 % | * | | | |

* Ej ackrediterad analys / Not accredited analysis

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BIC/SWIFT: SWEDSESS

Image courtesy of [Det Norske Veritas]

# D-LAB

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## Provningsresultat / Test Results:

3 (3)

Ordernr / Orderno: DL-70664

| Beställare / Client | Referens / Reference |
|---|---|
| DNV GL AS | [redacted] |

Adress / Address: P.O. Box 300,Org. ID No: 945748931MVA, NO-1322 HÖVIK

| Er beställning / Your order No | Ankomstdag / Sample Registration Date | Utskriftsdatum / Date of issue | DL ID |
|---|---|---|---|
| 10299927 | 2021-09-10 | 2021-09-13 | 695981 |

Provbeteckning / Sample identity: 3-1

Noteringar / Notes:

| Resultat/ Results | | Mätosäkerhet/ Uncertainty of measurement | Ackrediterat mätområde Accredited range of measurement | Standard metod Standard method | Dlab metod/ Dlab method |
|---|---|---|---|---|---|
| C | 0.231 % | 0.009 % | 0.0020 - 5.0 % | ASTM E 1019-18 | 5.4-058M |
| Si | 0.23 % | 0.007 % | 0.01 - 4 % | ASTM E 572-13 | 5.4-054M |
| Mn | 1.26 % | 0.009 % | 0.01 - 15 % | ASTM E 572-13 | 5.4-054M |
| P | 0.015 % | 0.002 % | 0.002 - 0.05 % | ASTM E 1086-14 | 5.4-057M |
| S | 0.005 % | 0.001 % | 0.0010 - 0.35 % | ASTM E 1019-18 | 5.4-058M |
| Cr | 0.58 % | 0.002 % | 0.01 - 30 % | ASTM E 572-13 | 5.4-054M |
| Ni | 0.49 % | 0.004 % | 0.01 - 40 % | ASTM E 572-13 | 5.4-054M |
| Mo | 0.25 % | 0.007 % | 0.01 - 8 % | ASTM E 572-13 | 5.4-054M |
| Ti | 0.003 % | 0.002 % | 0.003 - 2 % | ASTM E 572-13 | 5.4-054M |
| Nb | <0.005 % | * | 0.005 - 2 % | ASTM E 572-13 | 5.4-054M |
| Cu | 0.14 % | 0.002 % | 0.010 - 4 % | ASTM E 572-13 | 5.4-054M |
| Co | <0.005 % | * | 0.005 - 16 % | ASTM E 572-13 | 5.4-054M |
| N | 0.009 % | 0.001 % | 0.0002 - 0.50 % | ASTM E 1019-18 | 5.4-061M |
| Sn | 0.009 % | 0.0005 % | 0.002 - 0.1 % | ASTM E 572-13 | 5.4-054M |
| W | <0.01 % | * | 0.01 - 17 % | ASTM E 572-13 | 5.4-054M |
| V | 0.063 % | 0.001 % | 0.005 - 4 % | ASTM E 572-13 | 5.4-054M |
| Al | 0.025 % | 0.005 % | 0.01 - 0.3 % | ASTM E 1086-14 | 5.4-057M |
| Ta | <0.002 % | * | | | |
| Ca | 0.0009 % | * | | | |
| B | 0.0003 % | 0.00006 % | 0.0002 - 0.005 % | ASTM E 1086-14 | 5.4-057M |
| As | 0.004 % | 0.0005 % | 0.001 - 0.030 % | ASTM E 1086-14 | 5.4-057M |
| Fe | 96.66 % | * | | | |

* Ej ackrediterad analys / Not accredited analysis

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# Provningsresultat / Test Results:

Ordernr / Orderno
DL-70664

| Beställare / Client | Referens / Reference |
|---|---|
| DNV GL AS | [redacted] |
| Adress / Address: P.O. Box 300,Org. ID No: 945748931MVA, NO-1322 HÖVIK | |

| Er beställning / Your order No | Ankomstdag / Sample Registration Date | Utskriftsdatum / Date of issue | DL ID |
|---|---|---|---|
| 10299927 | 2021-09-10 | 2021-09-13 | 695982 |

Provbeteckning / Sample identity: 5-10

Noteringar / Notes:

| Resultat/ Results | | Mätosäkerhet/ Uncertainty of measurement | Ackrediterat mätområde Accredited range of measurement | Standard metod Standard method | Dlab metod/ Dlab method |
|---|---|---|---|---|---|
| C | 0.236 % | 0.010 % | 0.0020 - 5.0 % | ASTM E 1019-18 | 5.4-058M |
| Si | 0.23 % | 0.007 % | 0.01 - 4 % | ASTM E 572-13 | 5.4-054M |
| Mn | 1.25 % | 0.009 % | 0.01 - 15 % | ASTM E 572-13 | 5.4-054M |
| P | 0.015 % | 0.002 % | 0.002 - 0.05 % | ASTM E 1086-14 | 5.4-057M |
| S | 0.005 % | 0.001 % | 0.0010 - 0.35 % | ASTM E 1019-18 | 5.4-058M |
| Cr | 0.58 % | 0.002 % | 0.01 - 30 % | ASTM E 572-13 | 5.4-054M |
| Ni | 0.49 % | 0.004 % | 0.01 - 40 % | ASTM E 572-13 | 5.4-054M |
| Mo | 0.25 % | 0.007 % | 0.01 - 8 % | ASTM E 572-13 | 5.4-054M |
| Ti | 0.003 % | 0.002 % | 0.003 - 2 % | ASTM E 572-13 | 5.4-054M |
| Nb | <0.005 % | * | 0.005 - 2 % | ASTM E 572-13 | 5.4-054M |
| Cu | 0.14 % | 0.002 % | 0.010 - 4 % | ASTM E 572-13 | 5.4-054M |
| Co | <0.005 % | * | 0.005 - 16 % | ASTM E 572-13 | 5.4-054M |
| N | 0.008 % | 0.001 % | 0.0002 - 0.50 % | ASTM E 1019-18 | 5.4-061M |
| Sn | 0.009 % | 0.0005 % | 0.002 - 0.1 % | ASTM E 572-13 | 5.4-054M |
| W | <0.01 % | * | 0.01 - 17 % | ASTM E 572-13 | 5.4-054M |
| V | 0.061 % | 0.001 % | 0.005 - 4 % | ASTM E 572-13 | 5.4-054M |
| Al | 0.026 % | 0.005 % | 0.01 - 0.3 % | ASTM E 1086-14 | 5.4-057M |
| Ta | <0.002 % | * | | | |
| Ca | 0.0008 % | * | | | |
| B | 0.0003 % | 0.00006 % | 0.0002 - 0.005 % | ASTM E 1086-14 | 5.4-057M |
| As | 0.004 % | 0.0005 % | 0.001 - 0.030 % | ASTM E 1086-14 | 5.4-057M |
| Fe | 96.67 % | * | | | |

* Ej ackrediterad analys / Not accredited analysis
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# Provningsresultat / Test Results:

Ordernr / Orderno: DL-70664

| Beställare / Client | Referens / Reference |
|---|---|
| DNV GL AS | [redacted] |

Adress / Address: P.O. Box 300,Org. ID No: 945748931MVA, NO-1322 HÖVIK

| Er beställning / Your order No | Ankomstdag / Sample Registration Date | Utskriftsdatum / Date of issue | DL ID |
|---|---|---|---|
| 10299927 | 2021-09-10 | 2021-09-13 | 695983 |

Provbeteckning / Sample identity: Fractured link

Noteringar / Notes:

| Resultat/ Results | | Mätosäkerhet/ Uncertainty of measurement | Ackrediterat mätområde Accredited range of measurement | Standard metod Standard method | Dlab metod/ Dlab method |
|---|---|---|---|---|---|
| C | 0.226 % | 0.009 % | 0.0020 - 5.0 % | ASTM E 1019-18 | 5.4-058M |
| Si | 0.23 % | 0.007 % | 0.01 - 4 % | ASTM E 572-13 | 5.4-054M |
| Mn | 1.25 % | 0.009 % | 0.01 - 15 % | ASTM E 572-13 | 5.4-054M |
| P | 0.015 % | 0.002 % | 0.002 - 0.05 % | ASTM E 1086-14 | 5.4-057M |
| S | 0.004 % | 0.001 % | 0.0010 - 0.35 % | ASTM E 1019-18 | 5.4-058M |
| Cr | 0.58 % | 0.002 % | 0.01 - 30 % | ASTM E 572-13 | 5.4-054M |
| Ni | 0.49 % | 0.004 % | 0.01 - 40 % | ASTM E 572-13 | 5.4-054M |
| Mo | 0.25 % | 0.007 % | 0.01 - 8 % | ASTM E 572-13 | 5.4-054M |
| Ti | 0.003 % | 0.002 % | 0.003 - 2 % | ASTM E 572-13 | 5.4-054M |
| Nb | <0.005 % | * | 0.005 - 2 % | ASTM E 572-13 | 5.4-054M |
| Cu | 0.14 % | 0.002 % | 0.010 - 4 % | ASTM E 572-13 | 5.4-054M |
| Co | <0.005 % | * | 0.005 - 16 % | ASTM E 572-13 | 5.4-054M |
| N | 0.009 % | 0.001 % | 0.0002 - 0.50 % | ASTM E 1019-18 | 5.4-061M |
| Sn | 0.008 % | 0.0005 % | 0.002 - 0.1 % | ASTM E 572-13 | 5.4-054M |
| W | <0.01 % | * | 0.01 - 17 % | ASTM E 572-13 | 5.4-054M |
| V | 0.061 % | 0.001 % | 0.005 - 4 % | ASTM E 572-13 | 5.4-054M |
| Al | 0.024 % | 0.005 % | 0.01 - 0.3 % | ASTM E 1086-14 | 5.4-057M |
| Ta | <0.002 % | * | | | |
| Ca | 0.0009 % | * | | | |
| B | 0.0005 % | 0.00008 % | 0.0002 - 0.005 % | ASTM E 1086-14 | 5.4-057M |
| As | 0.004 % | 0.0005 % | 0.001 - 0.030 % | ASTM E 1086-14 | 5.4-057M |
| Fe | 96.68 % | * | | | |

* Ej ackrediterad analys / Not accredited analysis
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BIC/SWIFT: SWEDSESS

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## Provningsresultat / Test Results:

| Revision | Ordernr / Orderno |
|---|---|
| rev. 1 | DL-72498 |

| Beställare / Client | Referens / Reference |
|---|---|
| DNV GL AS | [redacted] |

Adress / Address
P.O. Box 300,Org. ID No: 945748931MVA, NO-1322 HÖVIK

| Er beställning / Your order No | Ankomstdag / Sample Registration Date | Utskriftsdatum / Date of issue | DL ID |
|---|---|---|---|
| SAKNAS | 2021-12-09 | 2021-12-10 | 703062 |

Provbeteckning / Sample identity
SB/1

Noteringar / Notes

| Resultat/ Results | | Mätosäkerhet/ Uncertainty of measurement | Ackrediterat mätområde Accredited range of measurement | Standard metod Standard method | Dlab metod/ Dlab method |
|---|---|---|---|---|---|
| C | 0.420 % | 0.02 % | 0.0020 - 5.0 % | ASTM E 1019-18 | 5.4-058M |
| Si | 0.33 % | 0.008 % | 0.01 - 4 % | ASTM E 572-13 | 5.4-054M |
| Mn | 0.81 % | 0.007 % | 0.01 - 15 % | ASTM E 572-13 | 5.4-054M |
| P | 0.020 % | 0.003 % | 0.002 - 0.05 % | ASTM E 1086-14 | 5.4-057M |
| S | 0.041 % | 0.005 % | 0.0010 - 0.35 % | ASTM E 1019-18 | 5.4-058M |
| Cr | 1.07 % | 0.004 % | 0.01 - 30 % | ASTM E 572-13 | 5.4-054M |
| Ni | 0.02 % | 0.002 % | 0.01 - 40 % | ASTM E 572-13 | 5.4-054M |
| Mo | 0.19 % | 0.007 % | 0.01 - 8 % | ASTM E 572-13 | 5.4-054M |
| Ti | 0.003 % | 0.002 % | 0.003 - 2 % | ASTM E 572-13 | 5.4-054M |
| Nb | < 0.005 % | * | 0.005 - 2 % | ASTM E 572-13 | 5.4-054M |
| Cu | 0.054 % | 0.002 % | 0.010 - 4 % | ASTM E 572-13 | 5.4-054M |
| Co | < 0.005 % | * | 0.005 - 16 % | ASTM E 572-13 | 5.4-054M |
| N | 0.005 % | 0.001 % | 0.0002 - 0.50 % | ASTM E 1019-18 | 5.4-061M |
| Sn | 0.005 % | 0.0005 % | 0.002 - 0.1 % | ASTM E 572-13 | 5.4-054M |
| W | < 0.01 % | * | 0.01 - 17 % | ASTM E 572-13 | 5.4-054M |
| V | 0.005 % | 0.0009 % | 0.005 - 4 % | ASTM E 572-13 | 5.4-054M |
| Al | 0.019 % | 0.004 % | 0.01 - 0.3 % | ASTM E 1086-14 | 5.4-057M |
| Ta | < 0.002 % | * | | ASTM E 1086-14 | 5.4-057M |
| Ca | 0.0021 % | * | | ASTM E 1086-14 | 5.4-057M |
| B | 0.0004 % | 0.00007 % | 0.0002 - 0.005 % | ASTM E 1086-14 | 5.4-057M |
| As | 0.003 % | 0.0004 % | 0.001 - 0.030 % | ASTM E 1086-14 | 5.4-057M |
| Fe | 97.00 % | * | | | |

* Ej ackrediterad analys / Not accredited analysis
The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor of k=2, providing a level of confidence of approximately 95%

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Email: info@degerforslab.se

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DNV

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2 (2)

## Provningsresultat / Test Results:

| Revision | Ordernr / Orderno |
|---|---|
| rev. 1 | DL-72498 |

| Beställare / Client | Referens / Reference |
|---|---|
| DNV GL AS | [redacted] |

Adress / Address
P.O. Box 300,Org. ID No: 945748931MVA, NO-1322 HÖVIK

| Er beställning / Your order No | Ankomstdag / Sample Registration Date | Utskriftsdatum / Date of issue | DL ID |
|---|---|---|---|
| SAKNAS | 2021-12-09 | 2021-12-10 | 703063 |

Provbeteckning / Sample identity
Port/3

Noteringar / Notes

| Resultat/ Results | | Mätosäkerhet/ Uncertainty of measurement | Ackrediterat mätområde Accredited range of measurement | Standard metod Standard method | Dlab metod/ Dlab method |
|---|---|---|---|---|---|
| C | 0.154 % | 0.007 % | 0.0020 - 5.0 % | ASTM E 1019-18 | 5.4-058M |
| Si | 0.03 % | * | - | ASTM E 1086-14 | 5.4-057M |
| Mn | 1.09 % | * | - | ASTM E 1086-14 | 5.4-057M |
| P | 0.010 % | 0.002 % | 0.002 - 0.05 % | ASTM E 1086-14 | 5.4-057M |
| S | 0.015 % | 0.002 % | 0.0010 - 0.35 % | ASTM E 1019-18 | 5.4-058M |
| Cr | 0.03 % | * | - | ASTM E 1086-14 | 5.4-057M |
| Ni | 0.02 % | * | - | ASTM E 1086-14 | 5.4-057M |
| Mo | < 0.01 % | * | - | ASTM E 1086-14 | 5.4-057M |
| Ti | < 0.001 % | * | - | ASTM E 1086-14 | 5.4-057M |
| Nb | < 0.002 % | * | - | ASTM E 1086-14 | 5.4-057M |
| Cu | 0.017 % | * | - | ASTM E 1086-14 | 5.4-057M |
| Co | < 0.01 % | * | 0.01 - 0.35 % | ASTM E 1086-14 | 5.4-057M |
| Sn | < 0.002 % | * | - | ASTM E 1086-14 | 5.4-057M |
| W | 0.004 % | * | - | ASTM E 1086-14 | 5.4-057M |
| V | < 0.003 % | * | - | ASTM E 1086-14 | 5.4-057M |
| Al | 0.004 % | * | 0.01 - 0.3 % | ASTM E 1086-14 | 5.4-057M |
| Ta | < 0.002 % | * | | ASTM E 1086-14 | 5.4-057M |
| Ca | < 0.0005 % | * | | ASTM E 1086-14 | 5.4-057M |
| B | < 0.0002 % | * | 0.0002 - 0.005 % | ASTM E 1086-14 | 5.4-057M |
| As | 0.005 % | 0.0006 % | 0.001 - 0.030 % | ASTM E 1086-14 | 5.4-057M |
| N | < 0.002 % | * | 0.0002 - 0.50 % | ASTM E 1019-18 | 5.4-061M |
| Fe | 98.61 % | * | | | |

* Ej ackrediterad analys / Not accredited analysis
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**DEGERFORS LABORATORIUM**

[redacted]

Rapporten är signerad digitalt
The raport is digitally signed

Laborant

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Bank: Swedbank, Degerfors
IBAN: SE64800081736296357

Image courtesy of Det Norske Veritas

# APPENDIX E
## Certificate of calibration, 28.5 MN tensile tester

DNV

MPA NRW.

Materialprüfungsamt Nordrhein-Westfalen

PRÜFEN · ÜBERWACHEN · ZERTIFIZIEREN

akkreditiert durch die / *accredited by the*

**Deutsche Akkreditierungsstelle GmbH**

ilac-MRA · DAkkS Deutsche Akkreditierungsstelle D-K-11142-01-00

als Kalibrierlaboratorium im / *as calibration laboratory in the*

**Deutschen Kalibrierdienst** DKD

Kalibrierschein
*Calibration certificate*

Kalibrierzeichen
*Calibration mark*

| |
|---|
| W 0723-1 |
| D-K-11142-01-00 |
| 2018-04 |

| | |
|---|---|
| Gegenstand<br>*Object* | Zugprüfmaschine, liegend / *tension testing machine, horizontally* |
| Hersteller<br>*Manufacturer* | MFL Prüf- u. Messsysteme, Schifferstadt / MessTek, Ludwigshafen |
| Typ<br>*Type* | LZED |
| Fabrikat/Serien-Nr.<br>*Serial number* | 000192 |
| Auftraggeber<br>*Customer* | DNV GL AS<br>Damsgårdsveien 111<br>N-5058 Bergen / Norway |
| Auftragsnummer<br>*Order No.* | 43 0723 18-1 |
| Anzahl der Seiten des Kalibrierscheines<br>*Number of pages of the certificate* | 8 |
| Datum der Kalibrierung<br>*Date of calibration* | 2018-04-10 |

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

*This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).*
*The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.*
*The user is obliged to have the object recalibrated at appropriate intervals.*

Dieser Kalibrierschein darf nur vollständig und unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung sowohl der Deutschen Akkreditierungsstelle GmbH als auch des ausstellenden Kalibrierlaboratoriums. Kalibrierscheine ohne Unterschrift haben keine Gültigkeit.

*This calibration certificate may not be reproduced other than in full except with the permission of both the Deutsche Akkreditierungsstelle GmbH and the issuing laboratory. Calibration certificates without signature are not valid.*

| Datum<br>*Date* | Stellv. Leiter des Kalibrierlaboratoriums<br>*Deputy head of the calibration laboratory* | Bearbeiter<br>*Person in charge* |
|---|---|---|
| 2018-04-23 | [redacted] | [redacted] |

D-Nr.: 0723_W_001_0011_22_04_18.doc

| | | | |
|---|---|---|---|
| Hausanschrift<br>Marsbruchstraße 186<br>D-44287 Dortmund<br>Telefon (0231) 45 02-0<br>Telefax (0231) 45 85 49<br>E-Mail: info@mpanrw.de | Bahnstation: Dortmund-Hbf.<br>Telegramme: prüfamt Dortmund<br>Öffentliche Verkehrsmittel<br>Stadtbahn U47 ab Hbf.<br>Richtung Aplerbeck<br>bis „Allerstraße" | Außenstelle Erwitte<br>Auf den Thränen<br>D-59597 Erwitte<br>Telefon (0 29 43) 897-0<br>Telefax (0 29 43) 897-33<br>E-Mail: info@mpanrw.de | Bankverbindungen<br>Deutsche Bundesbank Filiale Dortmund<br>IBAN DE 14440000000044001815<br>BIC MARKDEF 1440<br>BLZ 440 000 00<br>Kto. 440 018 15 |

DNV



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PRÜFEN · ÜBERWACHEN · ZERTIFIZIEREN

| W 0723-1 |
| --- |
| D-K 11142-01-00 |
| 2018-04 |

## 1. Kalibriergegenstand / *calibration object*

| | |
| --- | --- |
| Gegenstand / *object*: | Zugprüfmaschine, liegend / *tension testing machine, horizontally* |
| Standort der Maschine / *location of the machine*: | Prüfhalle - Bergen / *testing hall - Bergen* / I Damsgårdsveien 111, Bergen |
| Bauart/Typ / *model/type* | - / LZED |
| Fabrikat/Seriennummer / *serial number*: | 000192 |
| Inventarnummer / *inventory number*: | - / - |
| Baujahr / *year of construction*: | 1983 |
| Antrieb / *drive mechanism*: | Hydraulisch, Motorpumpe / *hydraulically, motor pump* |
| Kraft-Aufnehmer / *force transducer*: | Elektr. Kraftaufnehmer (DMS an der Kolbenstange) / *electric force transducer (strain gauges at piston rod)* |
| Serien-Nr./Hersteller / *serial No./manufacturer*: | Force 1; Force 2 / - |
| Kraft-Anzeige / *force indication*: | Ziffernanzeige (Monitor) / *numeric display (monitor)* |
| Serien-Nr./Hersteller / *serial No./manufacturer*: | - / - |
| Zusatzeinrichtung / *additional components*: | - / - |
| Kraftanzeigebereiche / *load indication range*: | 28500 kN Zug / *tension* |
| Maximale Einbauhöhe / Einbaulänge / *max. daylight / total length*: | - / - |
| Pendelscheibenmassen / *pendulum-disc masses*: | - / - |
| weiterer Hersteller / *further manufacturer*: | MessTek, Ludwigshafen |
| Baujahr weiterer Hersteller / *year of construction further manufacturer*: | - / - |
| Seriennummer weiterer Hersteller / *serial number further manufacturer*: | - / - |

## 2. Kalibrierverfahren / *calibration procedure*

Die Prüfmaschine wurde gemäß DIN EN ISO 7500-1:2016-05 in 4 Messbereich(en) überprüft und kalibriert. / *The testing machine was inspected and calibrated in accordance with DIN EN ISO 7500-1:2016-05 in 4 measuring range(s).*

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## 3. Ort der Kalibrierung / *location of calibration*

Die Überprüfung und Kalibrierung erfolgte am oben genannten Standort. / *The inspection and calibration was carried out at the above-mentioned location.*

## 4. Messbedingungen / *measurement conditions*

- / -

## 5. Umgebungsbedingungen / *ambient conditions*

Raumtemperatur / *room temperature*: Siehe Zahlentafel(n) / *see data sheet(s)*

## 6. Messergebnisse / *measurement results*

### 6.1 Allgemeine Überprüfung der Maschine / *general inspection of the testing machine*

a) Zustand und Funktion / *behaviour and function*

- Traversenführungen / *crosshead guides*
- Aufstellung der Maschine / *mounting of the machine*
- Führungsrollen / *guiding rolls*
- Krafteinleitungsstelle / *parts of the drive mechanism*
- Verbindung von Säule u. Traversen / *fasteners on columns and crossheads*
- ruckfreier Antrieb / *uniform variation of the force*
- Kennzeichnung der Pendelscheibenmassen / *identification marking of the masses of pendulum*
- axiale Ausrichtung / *axial alignment*

b) Umgebungseinflüsse / *influences of the environmental conditions*

- Erschütterungen / *vibrations*
- aggressive Medien / *agressive media*
- einseitige Temperatureinflüsse / *temperature influences from one side*

c) Druckplatten / *pressure plates*

- Ebenheit / *evenness*
- Härte / *hardness*
- Beweglichkeit/Spiel / *mobility/stroke*
- Durchbiegung bei Höchstkraft / *bend under max. force*

d) Überprüfung des relativen Biegeeinflusses $f_v$ / *verification of relative influence of bending* $f_v$

Überprüfte Positionen: / *inspected positions:* a, b

Die Überprüfung ergab keine Beanstandungen. / *The verification did not result in objections.*

Bemerkungen / *remarks*: - / -

## 6.2 Kalibrierung der Kraftmesseinrichtung / *calibration of the force measuring device*

a) Beurteilte Kraftanzeigebereiche und deren Auflösungsvermögen / *evaluated load indication ranges and their resolution*

| Kraftanzeigebereich $F_N$<br>*load indication range $F_N$* | Anzeige $F_i$ von<br>*Indicated force $F_i$ from* | bis<br>*to* | Auflösung r*)<br>*resolution r*)* | Ableseunsicherheit $a$ ≤ % von $F_i$<br>*relative resolution $a$ ≤ % of $F_i$* | Zugehörige(r) elektr. Kraftaufnehmer (DMS an der Kolbenstange)<br>*used electric force transducer (strain gauges at piston rod)* |
|---|---|---|---|---|---|
| 28500 kN | 200 kN | 20000 kN | 1 kN | 0,5 | Force 1 |
| 28500 kN | 200 kN | 20000 kN | 1 kN | 0,5 | Force 2 |

*) Auflösung
r = 1 Ziffernschritt bzw.
r = 1 Skalenteilungswert/schätzbarer Bruchteil eines Skalenteilungswertes
Wenn die Anzeige schwankt (siehe Bemerkungen):
r = halbe Schwankungsbreite plus 1 Ziffernschritt

**) Resolution*
*r = 1 digital step or*
*r = 1 partition of scale/estimable part of the partition of scale*
*If the display fluctuates (see remark):*
*r = half of the limits of variation plus 1 digital step*

b) Die relative Nullpunktabweichung $f_0$ entspricht in den kalibrierten Kraft-Anzeigebereichen den Anforderungen der jeweils zugelassenen Klasse. / *The relative zero error $f_0$ fulfils the requirements of the respective admitted classes according to the tested indication ranges.*

c) Ermittlung / *determination of*

- der relativen Anzeigeabweichung $q$ / *the relative display deviation q*
- der relativen Wiederholpräzision $b$ / *the relative repeatability b*
- der relativen Umkehrspanne $u$ / *the relative reversal error u*
- des Einflusses der Zusatzeinrichtung / *the influence of the additional device*

Bemerkungen / *remarks*:

Die Abweichung der Messwerte ≥ 16500 kN sind aus extrapolierten Sollwerten des ZSt 25000/1 - K 2126 ermittelt. / *The deviation of the measured values ≥ 16500 kN were determined from extrapolated reference values of ZSt 25000/1 - K 2126.*

Zur Berechnung der "Kraft-Kennlinie" verwendet der Rechner bestimmte Faktoren, bei deren Änderung der Kalibrierschein des MPA NRW seine Gültigkeit verliert. / *When calculating the "force characteristic line", the computer utilizes certain factors; altering these factors causes the calibration certificate of the MPA NRW to lose its validity.*

Der Kalibrierung am 2018-04-10 lagen folgende Kalibrierfaktoren zugrunde: / *The calibration on 2018-04-10 underlay the following calibration factors:*

Sensitivity Force 1: 3162 kN/V

Sensitivity Force 2: 3155 kN/V

## 6.3 Zahlentafel(n) / *data sheet(s)*

**Force 1**

Messbereich / *measuring range:* 28500 kN Zug / *tension*

Kalibrierdatum / *date of calibration:* 2018-04-10

Temperatur / *temperature:* (19,2 ± 0,6) °C

weitere Angaben / *additional details:* Force 1

| | | | Hauptreihen / *main test series* | | | ergänzende Messreihe / *additional test series* | | |
|---|---|---|---|---|---|---|---|---|
| $F_i$ | $F$ | $r$ | $q$ | $b$ | $u$ | $q$ | $b$ | $W_{(k=2)}$ |
| Maschinenanzeige *machine display* kN | richtige Kraft *measured force* kN | Auflösung *resolution* kN | Anzeigeabweichung *display deviation* % | Wiederholpräzision *repeatability* % | Umkehrspanne *reversal error* % | Anzeigeabweichung *display deviation* % | Wiederholpräzision *repeatability* % | Messunsicherheit *uncertainty of measurement* % |
| 200 | 199,8 | 1 | 0,12 | 0,49 | - | - | - | 0,44 |
| 400 | 397,3 | 1 | 0,68 | 0,41 | - | - | - | 0,30 |
| 500 | 497,9 | 1 | 0,43 | 0,13 | - | - | - | 0,19 |
| 800 | 796,0 | 1 | 0,50 | 0,19 | - | - | - | 0,18 |
| 1400 | 1397,1 | 1 | 0,21 | 0,10 | - | - | - | 0,14 |
| 2000 | 2000,0 | 1 | 0,00 | 0,05 | - | - | - | 0,13 |
| 2000 | 2000,7 | 1 | -0,04 | 0,04 | - | - | - | 0,13 |
| 4000 | 4008,0 | 1 | -0,20 | 0,02 | - | - | - | 0,12 |
| 8000 | 8014,1 | 1 | -0,18 | 0,01 | - | - | - | 0,12 |
| 12000 | 12012,8 | 1 | -0,11 | 0,00 | - | - | - | 0,12 |
| 16000 | 16006,4 | 1 | -0,04 | 0,00 | - | - | - | 0,12 |
| 20000 | 20000,8 | 1 | 0,00 | 0,00 | - | - | - | 0,12 |

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| W 0723-1 |
|---|
| D-K-11142-01-00 |
| 2018-04 |

D-Nr.: 0725_W_001_0001_22_04_18.doc

Der Kalibrierung am 2018-04-10 lagen folgende Kalibrierfaktoren zugrunde: / *The calibration on 2018-04-10 underlay the following calibration factors:*

Sensitivity Force 1: 3162 kN/V

Sensitivity Force 2: 3155 kN/V

## 6.3 Zahlentafel(n) / *data sheet(s)*

**Force 1**

Messbereich / *measuring range:* 28500 kN Zug / *tension*

Kalibrierdatum / *date of calibration:* 2018-04-10

Temperatur / *temperature:* (19,2 ± 0,6) °C

weitere Angaben / *additional details:* Force 1

| | | | Hauptreihen / *main test series* | | | ergänzende Messreihe / *additional test series* | | |
|---|---|---|---|---|---|---|---|---|
| $F_i$ | $F$ | $r$ | $q$ | $b$ | $u$ | $q$ | $b$ | $W_{(k=2)}$ |
| Maschinen-anzeige *machine display* kN | richtige Kraft *measured force* kN | Auflösung *resolution* kN | Anzeige-abweichung *display deviation* % | Wiederhol-präzision *repeatability* % | Umkehr-spanne *reversal error* % | Anzeige-abweichung *display deviation* % | Wiederhol-präzision *repeatability* % | Messun-sicherheit *uncertainty of measurement* % |
| 200 | 199,8 | 1 | 0,12 | 0,49 | - | - | - | 0,44 |
| 400 | 397,3 | 1 | 0,68 | 0,41 | - | - | - | 0,30 |
| 500 | 497,9 | 1 | 0,43 | 0,13 | - | - | - | 0,19 |
| 800 | 796,0 | 1 | 0,50 | 0,19 | - | - | - | 0,18 |
| 1400 | 1397,1 | 1 | 0,21 | 0,10 | - | - | - | 0,14 |
| 2000 | 2000,0 | 1 | 0,00 | 0,05 | - | - | - | 0,13 |
| 2000 | 2000,7 | 1 | -0,04 | 0,04 | - | - | - | 0,13 |
| 4000 | 4008,0 | 1 | -0,20 | 0,02 | - | - | - | 0,12 |
| 8000 | 8014,1 | 1 | -0,18 | 0,01 | - | - | - | 0,12 |
| 12000 | 12012,8 | 1 | -0,11 | 0,00 | - | - | - | 0,12 |
| 16000 | 16006,4 | 1 | -0,04 | 0,00 | - | - | - | 0,12 |
| 20000 | 20000,8 | 1 | 0,00 | 0,00 | - | - | - | 0,24 |

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**Force 2**

Messbereich / *measuring range:* 28500 kN Zug / *tension*

Kalibrierdatum / *date of calibration:* 2018-04-10

Temperatur / *temperature:* (19,8 ± 0,6) °C

weitere Angaben / *additional details:* Force 2

| | | | Hauptreihen / *main test series* | | | ergänzende Messreihe / *additional test series* | | |
|---|---|---|---|---|---|---|---|---|
| $F_i$ | $F$ | $r$ | $q$ | $b$ | $u$ | $q$ | $b$ | $W_{(k=2)}$ |
| Maschinen-anzeige *machine display* kN | richtige Kraft *measured force* kN | Auflösung *resolution* kN | Anzeige-abweichung *display deviation* % | Wiederhol-präzision *repeatability* % | Umkehr-spanne *reversal error* % | Anzeige-abweichung *display deviation* % | Wiederhol-präzision *repeatability* % | Messun-sicherheit *uncertainty of measurement* % |
| 200 | 200,41 | 1,0 | -0,20 | 0,38 | - | - | - | 0,41 |
| 400 | 396,60 | 1,0 | 0,86 | 0,36 | - | - | - | 0,29 |
| 500 | 495,97 | 1,0 | 0,81 | 0,27 | - | - | - | 0,23 |
| 800 | 793,15 | 1,0 | 0,86 | 0,21 | - | - | - | 0,19 |
| 1400 | 1392,49 | 1,0 | 0,54 | 0,08 | - | - | - | 0,14 |
| 2000 | 1994,92 | 1,0 | 0,25 | 0,06 | - | - | - | 0,13 |
| 2000 | 1994,27 | 1,0 | 0,29 | 0,08 | - | - | - | 0,13 |
| 4000 | 4001,50 | 1,0 | -0,04 | 0,06 | - | - | - | 0,13 |
| 8000 | 8009,39 | 1,0 | -0,12 | 0,03 | - | - | - | 0,12 |
| 12000 | 12009,28 | 1,0 | -0,08 | 0,02 | - | - | - | 0,12 |
| 16000 | 16004,34 | 1,0 | -0,03 | 0,02 | - | - | - | 0,12 |
| 20000 | 20001,25 | 1,0 | -0,01 | 0,01 | - | - | - | 0,24 |

## 7. Messunsicherheit / *uncertainty of measurement*

Angegeben ist die erweiterte Messunsicherheit, die sich aus der Standardmessunsicherheit durch Multiplikation mit dem Erweiterungsfaktor k = 2 ergibt. Sie wurde gemäß DAkkS-DKD-3 unter Berücksichtigung von DIN EN ISO 7500-1 Anhang C ermittelt. Der Wert der Messgröße liegt mit einer Wahrscheinlichkeit von 95 % im zugeordneten Werteintervall. / *The measurement uncertainty that is stated results from the standard uncertainty multiplied by the coverage factor k = 2. It was calculated according to DAkkS-DKD-3 in consideration of DIN EN ISO 7500-1 Annex C. The value of the measurand lies with a probability of 95 % within the assigned range of values.*

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## 8. Konformitätsaussage / *conformance statement*

Die Prüfmaschine entspricht DIN EN ISO 7500-1:2016-05 und wurde wie folgt zugeordnet: / *The testing machine fulfils the requirements of DIN EN ISO 7500-1:2016-05 and was classified as follows:*

| Kraft-Messbereich *load measuring range* | von *from* | bis *to* | Klasse / *class* ohne Berücksichtigung der Messunsicherheit / *without considering the measurement uncertainty* | Klasse / *class* mit Berücksichtigung der Messunsicherheit* / *with considering the measurement uncertainty** | Bemerkungen / *remarks* |
|---|---|---|---|---|---|
| 28500 kN Zug / *tension* | 200 kN | 20000 kN | 1 | 1 | nur aufsteigende Prüfkräfte /*only ascending test loads* |

* unter Berücksichtigung des Beiblatts 4 der DIN EN ISO 7500-1 / *in consideration of supplementary sheet 4 of DIN EN ISO 7500-1*

Bemerkungen / *remarks*:
Die Prüfmaschine ist nur für aufsteigende Prüfkräfte kalibriert. / *The testing machine is only calibrated for ascending test loads.*

## 9. Hinweise / *references*

Nach DIN 51220 ist eine erneute Kalibrierung erforderlich „nach jeder Neuaufstellung (bei ortsgebundenen Maschinen), bei mutmaßlichen Veränderungen in der Beanspruchungseinrichtung, Verformungs-, Arbeits- oder Kraftmesseinrichtung, anschließend an jede Änderung, Ergänzung oder Überholung, die die Wirkungsweise der Prüfmaschine beeinflussen kann". Der Kalibrierschein darf nur vollständig veröffentlicht werden. Die auszugsweise Veröffentlichung bedarf der vorherigen Genehmigung des MPA NRW und der DAkkS. Dieses Dokument wurde ursprünglich in deutscher Sprache erstellt. Im Zweifel gilt die deutsche Fassung. / *According to DIN 51220 a re-verification becomes due after each re-setting up (of localised machines), in case of presumed changes of the load set-up, mechanism, deformation, work or force measuring instrument, after each change, addition or overhauling, which can affect the impact of the test equipment. This verification report may be published completely only, publication in extracts requires the prior permission of the MPA NRW and the DAkkS. This document was originally written in German. In cases of doubt the German version shall prevail.*

Die Deutsche Akkreditierungsstelle GmbH ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine. Die weiteren Unterzeichner innerhalb und außerhalb Europas sind den Internetseiten von EA (www.european-accreditation.org) und ILAC (www.ilac.org) zu entnehmen. / *The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates. The other signatories in Europe and beyond can be found at the websites of EA (www.european-accreditation.org) and ILAC (www.ilac.org).*

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## 10. Verwendete Mess- und Hilfseinrichtungen / *utilized measuring and auxiliary devices*

Die verwendeten Messeinrichtungen sind auf die nationalen Normale rückgeführt. / *The utilized measuring equipment has a certified traceability to national standards.*

| Bezeichnung / *designation* | K-Nr. / *identification number* | Bemerkungen / *remarks* |
|---|---|---|
| 25-MN-Zugkraftmessstab / *25 MN tension force measuring rod* | K 2126 / K 7186 | -- |
| Messverstärker MGCplus mit ML 38 / *carrier frequency amplifier with ML 38* | K 5417; K 5418; K 5419; K 5420 | -- |
| Thermometer / *thermometer* | K 7732 | -- |

Ende des Kalibrierscheins / *End of the calibration certificate*

Image courtesy of Det Norske Veritas

# APPENDIX F

## Test certificate, hardness

Image courtesy of Det Norske Veritas

32 x 96 kl.8 - 2 odc.x 50 m - George Taylor & Co. - zlecenie DE1/112/2019 - wysyłka Kwiecień 2019 r.

| | | | NR | NR | | | min.20 | min.1290 | | | | | | | Gatunek | | | | Kalibrowanie | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIESIĄC | Wielkość | DZIEŃ | PRÓBY | ŁAŃC | CECHA | Ep% | Ek [ % ] | Fz [ kN ] | R/P/Z | HB | GIĘCIE | WYTOP | SERIA | Dostawca | MATERIAŁU | Udar | Normal. | Pulsacja | Ł.zer | śr.siła | Norma | Klasa | metry | świad | m-c |
| luty | 96 | 20.02.19 | 46 | 9 | H52 8 3/19 | - | 38,5 | 1460 | W | 373 | +26 | 221071 | 3/19 | Mittal Steel | 23GHNMA+V | - | - | - | 0 | 820 | EN 818-2 | 8 | 100 | E-118/2019 | 4 |

[redacted]

Image courtesy of Det Norske Veritas

## About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.

DNV MJA/4 report no 2023-5163

Image courtesy of Det Norske Veritas

FAILURE OF CHAIN LINK ONBOARD CORNISHMAN

# Testing of reference chain sample MJA/4

## Marine Accident Investigation Branch

**Report No.:** 2023-5163, Rev. 0
**Document No.:** 1848477
**Date:** 2023-05-10

Image courtesy of Det Norske Veritas

| | | |
|---|---|---|
| Project name: | Failure of chain link onboard Cornishman | DNV AS Energy Systems |
| Report title: | Testing of reference chain sample MJA/4 | Materials & Testing - Bergen |
| Customer: | Marine Accident Investigation Branch, | Thormøhlensgt. 49A |
| | 1st Floor Spring Place | 5006 Bergen |
| | 105 Commercial Road | Norway |
| | SO15 1GH Southampton | Tel: +47 55 94 36 00 |
| | United Kingdom | 945 748 931 |
| Customer contact: | [redacted] | |
| Date of issue: | 2023-05-10 | |
| Project No.: | 10299927 | |
| Organisation unit: | Materials & Testing - Bergen-4100-NO | |
| Report No.: | 2023-5163, Rev. 0 | |
| Document No.: | 1848477 | |

Applicable contract(s) governing the provision of this Report:
PO 8000222944

Objective:

The objective of the performed testing has been to characterize the received chain and compare the results to previous testing of samples informed to be from the same heat number.

| Prepared by: | Verified by: | Approved by: |
|---|---|---|
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Keywords:
Lifting chain; Grade 8

| Rev. No. | Date | Reason for Issue | Prepared by | Verified by | Approved by |
|---|---|---|---|---|---|
| A | 2023-03-28 | Draft version for client comments | [redacted] | [redacted] | [redacted] |
| 0 | 2023-05-10 | First issue | [redacted] | [redacted] | [redacted] |

Image courtesy of Det Norske Veritas

# Table of contents

# 1 EXECUTIVE SUMMARY

DNV AS, Materials Bergen (DNV) has been requested by Marine Accident Investigation Branch (MAIB) to perform testing of a chain sample. The testing is part of a failure investigation of a similar chain link, performed by DNV AS in 2021 and presented in DNV Report 2021-5360 /1/.

## 1.1 Conclusions

Based on the performed examination and testing, the following is concluded:

- Marking on chain and chemical composition substantiate that the tested chain, MJA/4, comes from the same batch as previously tested chain samples, and corresponds to the received certificate.
- Break load testing confirms actual break load below certificate values and standard requirements.
- Variation in hardness, tensile and yield strength between different tested samples, and difference in actual break load and hardness when compared to certificate values, indicate higher variations in the properties of the chain compared to what is identified by the quality control of the manufacturer. The causes of the varying mechanical properties are most likely related to heat treatment.
- No unambiguous causes of the actual break load significantly below the certificate value and requirements have been identified. The reasons could be related to surface effects in the crown area, material properties (high hardness, partly high yield to tensile strength ratio), residual stresses, variations within the lot, etc. All these possibly contributing causes, are heavily dependent on the heat treatment process.

## 2 INTRODUCTION

DNV AS, Materials Bergen (DNV) has been requested by Marine Accident Investigation Branch (MAIB) to perform testing of a chain sample.

The background for the testing is a failure investigation of a similar chain, that was used as part of a quick release system onboard the trawler Cornishman. One of the chain links on the port side of the vessel fractured, causing the trawl fishing gear to fall down. The incident caused one fatality. The examination and testing of this chain and other relevant chain samples, both used and unused, are described in DNV Report 2021-5360 /1/. An overview of the different examined and tested chain samples and their history is given inTable 2-1.

**Table 2-1 Overview of chain samples, and their history.**

| Sample ID | Description | History of chain segment |
|---|---|---|
| Part MJA/4 | Unused section of chain | Unused, stored indoor in dry conditions |
| Part BJC/1 | Part of portside chain, connected to steel wire rope | Used onboard trawler from March 2020 until February 2021 |
| Part BJC/2 | Unused section of chain | Unused, stored on a pallet in a store located around 2-300 meters from the sea |
| Part BJC/3 | Starboard chain | Used onboard trawler from March 2020 until February 2021 |
| Part BJC/4 | Part of fractured link, portside chain | Used onboard trawler from March 2020 until February 2021 |
| Part BJC/5 | Part of portside chain, towards trawl | Used onboard trawler from March 2020 until February 2021 |

All chain samples are 32 mm diameter grade 8 short link chain, and the received certificate assumed to cover all samples is given in Appendix A. A test certificate giving the hardness of the chain is included in Appendix B. The certificate refers to the standards NS-EN ISO 818, Short link chain for lifting purposes – Safety – Part 2: Medium tolerance chain for chain slings - Grade 8 /2/ and ASTM A391, Standard Specification for Grade 80 Alloy Steel Chain /3/.

DNV

# 2 INTRODUCTION

DNV AS, Materials Bergen (DNV) has been requested by Marine Accident Investigation Branch (MAIB) to perform a failure investigation of a fractured chain.

The chain has been used as part of a quick release system onboard the trawler Cornishman. One of the chain links on the port side of the vessel fractured, causing the trawl fishing gear to fall down. The incident caused one fatality.

The incident occurred while the trawling system was not in use, however the weight of the system was supported by the quick release system.

## 2.1 Background

The principle of the quick release system is to release the trawl gear in an emergency, should the trawl gear cause the fishing vessel to become unstable. To achieve this, the trawl warp (a single wire that is attached to the towing bridle) is passed through a snatch block (or towing block), see an example of a similar system in Figure 2-1.

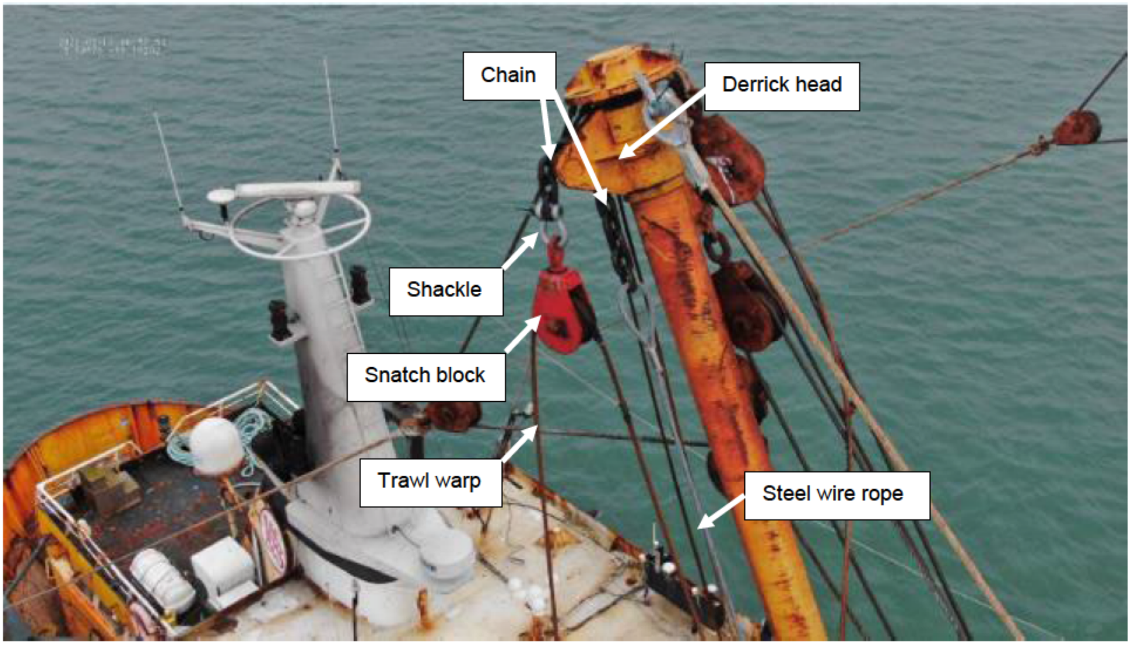


**Figure 2-1 Examples of quick release system similar to the one that failed. Image supplied by the client.**

The snatch block is suspended using a shackle on a chain that passes over a pin welded between cheek plates fitted to the derrick head. This chain failed.

The loading caused by towing the trawl along the seabed and lifting the trawl clear of the water is transmitted fully through the chain forming part of the quick release system. The Working Load Limit of the system is 8.4 tonnes.

The head of the derrick which supports the quick release chain has a limited degree of rotational freedom (ca. 60°) around the derrick allowing the lead of the snatch block and chain to move towards the load.

Similar systems are found on both sides of the vessel, and parts from both systems have been received for testing.

The chain is a 32 mm diameter grade 8 short link chain, and the received certificate is given in Appendix A. The certificate refers to the standards NS-EN ISO 818, Short link chain for lifting purposes – Safety – Part 2: Medium tolerance chain for chain slings - Grade 8 /1/ and ASTM A391, Standard Specification for Grade 80 Alloy Steel Chain /2/. The report has not assessed relevant requirements for the intended use.

In the chain certificate (given in Appendix A) the Measured breaking force is stated to be 1480 kN, which is 4.7 times the stated working load limit of 31.5 tons (equivalent to 314 kN). The minimum required breaking load is 1290 kN. The chain is also connected to a steel wire rope, with working load limit 8.4 tons. This steel wire rope is considered to be a weaker component compared to the chain.

The certificate is dated 2019-04-23. According to information from the client, the chains (both the starboard and the portside) has been in use from March 2020. i.e. approximately one year. The background for changing the chain at that time, and if the derrick heads were changed or refurbished at the same time is not known.

# 3 BASIS FOR WORK

An overview of the received parts is given in Table 3-1. The part ID's are given by the client.

**Table 3-1 Overview of received samples.**

| Part ID | Description |
|---|---|
| Part BJC/1 | Part of portside chain, connected to steel wire rope |
| Part BJC/2 | Unused section of chain |
| Part BJC/3 | Starboard chain |
| Part BJC/4 | Part of fractured link, portside chain |
| Part BJC/5 | Part of portside chain, towards trawl |
| MPH/CM/PORT/3 | Portside derrick head |
| MPH/CM/SB/1 | Starboard derrick head |

According to information from the client, the chain is bought in lengths of 8 meter and stored on a pallet in a store located around 2-300 meters from the sea. When a vessel asks for a replacement of the quick release gear, a length of chain is cut (10 - 13 links depending on the request) and then sent off to a contractor to prepare the quick release gear, by splicing the chain to the wire. The unused reference chain (Part BJC/2), has only been stored as described above.

## 3.1 Objective and scope of work

The main objective of the performed failure investigation has been to characterize the fracture and identify direct and underlying causes.

The performed examination has comprised:

- Review of relevant information
- Visual examination of all received parts
- NDT of all received chain links and derrick heads
- Material characterisation of single links and derrick heads:
    - Metallographic examination
    - Chemical analyses
    - Hardness testing
    - Estimation of tensile strength
    - Tensile testing (not derrick heads)
- Fractographic examination of fractured chain link
- Metallographic examination of fracture chain link
- Break load testing and visual examination of test samples

# 4 EXAMINATION AND CHARACTERISATION OF RECEIVED PARTS

## 4.1 Overview of received samples

Overview images showing the parts as received are given in Figure 4-1 to Figure 4-7. For all the chain samples, one of the ends were marked by DNV using a coloured plastic strip, to keep traceability of the two ends of each chain length. Different colours were used for the different samples.

**Figure 4-1 Sample BJC/1, part of portside chain, connected to steel wire rope. The upper image shows both chain and steel wire rope part, the lower image shows the chain at higher magnification.**

**Figure 4-2 Sample BJC/2, unused (reference) section of chain.**

**Figure 4-3 Sample BJC/3, starboard chain.**


**Figure 4-4 Sample BJC/4, part of fractured link, portside chain. The letters A and B is used further for identification of the two fracture surfaces.**

**Figure 4-5 Sample BJC/5, part of portside chain, towards trawl.**

## 3.5 Dimensional measurements

For all the chain links, measurements of the chain link diameter in the two crowns and on the straight leg without weld was measured, as well as the inside and outside length. The two crown diameters are denoted 1 closer to link 1 and 2 closer to link 8. For link 1 and 8 the crowns are denoted 1 and 2 arbitrarily, as the links are free to turn around. For crown diameter, the first diameter is measured in the length direction of the chain, the second diameter is measured perpendicular to the plane of the chain link, i.e. the first measurement will show the interlink wear.

The results are given in Table 3-1 together with relevant requirements, certificate values and results from previous testing. The inner length, outer length, diameter on non-weld leg and the minimum crown diameter are plotted in Figure 3-7 to Figure 3-10.

No significant dimensional difference between the currently examined chain links and the previously examined chain links is seen, except for the measurements in the crown indicating interlink wear on the used chain segments /1/.

Image courtesy of Det Norske Veritas

**Table 3-1 Dimension measurements for the different chain links.**

| Part ID | Description | Link no. | Inside length [mm] | Outside length [mm] | Diameter, crown 1 [mm] | Diameter crown 2 [mm] | Diameter, non-weld side [mm] |
|---|---|---|---|---|---|---|---|
| **Part MJA/4** | **Reference 2023** | 1 | 95.7 | 158.6 | 31.9/33.3* | 31.9/33.1* | 33.1 |
| | | 2 | 95.3 | 158.7 | 31.4/33.5 | 31.7/33.2 | 33.05 |
| | | 3 | 95.1 | 158.8 | 31.7/33.0 | 31.9/33.0 | 32.95 |
| | | 4 | 95.3 | 158.9 | 31.8/33.0 | 31.5/33.0 | 32.9 |
| | | 5 | 94.5 | 158.4 | 31.9/33.0 | 31.9/33.0 | 33.0 |
| | | 6 | 95.2 | 158.5 | 31.7/33.1 | 31.6/33.1 | 32.9 |
| | | 7 | 95.6 | 159.2 | 31.6/33.1 | 31.2/33.1 | 32.9 |
| | | 8 | 95.0 | 158.8 | 31.5/33.2* | 31.5/33.2* | 32.9 |
| **Certificate** | | | | | | | |
| **Results** | | | - | | - | - | 32.7 |
| **Requirements** | | | - | | | | 32 ± 1.6 |
| **Standards** | | | | | | | |
| **NS-EN ISO 818-2 /2/** | | | - | | | | 32 ± 1.6 |
| **ASTM A391M /3/** | | | Max. 102.4 | | - | - | Min. 31.04 |
| **Results from previous testing /1/** | | | | | | | |
| Part BJC/1 | Part of portside chain, connected to steel wire rope | 1 | 95.0 | 158.3 | 31.9 / 33.1* | 31.6 / 33.0* | 32.9 |
| | | 2 | 96.1 | 158.5 | 31.4 / 32.9 | 31.5 / 32.9 | 32.8 |
| | | 3 | 95.7 | 158.4 | 31.4 / 32.7 | 31.6 / 32.8 | 32.9 |
| | | 4 | 95.2 | 158.4 | 31.8 / 32.9 | 31.3 / 33.0 | 32.9 |
| | | 5 | 96.9 | 158.4 | 31.0 / 33.1* | 30.7 / 33.0* | 32.8 |
| Part BJC/2 | Unused section of chain** | 1 | 95.2 | 158.5 | 31.8 / 33.1* | 32.1 / 33.0* | 33.0 |
| | | 2 | 95.4 | 158.3 | 31.8 / 33.2 | 31.6 / 33.3 | 33.1 |
| | | 3 | 94.7 | 158.3 | 31.9 / 33.3 | 32.1 / 33.3 | 33.1 |
| | | 4 | 96.1 | 159.0 | 31.3 / 33.3 | 31.7 / 33.3 | 33.0 |
| | | 5 | 95.1 | 158.2 | 32.2 / 33.3 | 31.6 / 33.2 | 33.0 |
| | | 6 | 95.5 | 158.5 | 32.0 / 33.1 | 31.8 / 32.1 | 33.0 |
| | | 7 | 94.7 | 158.9 | 32.3 / 33.3 | 32.6 / 33.3 | 33.1 |
| | | 8 | 96.5 | 159.3 | 31.6 / 33.0 | 31.9 / 33.0 | 32.8 |
| | | 9 | 95.9 | 158.9 | 31.6 / 33.1* | 31.7 / 33.2* | 33.0 |
| Part BJC/3 | Starboard chain | 1 | 95.1 | 158.9 | 31.6 / 33.1* | 31.4 / 33.2* | 32.9 |
| | | 2 | 95.0 | 158.5 | 32.2 / 32.9 | 31.7 / 32.8 | 32.8 |
| | | 3 | 95.8 | 158.5 | 31.4 / 33.1 | 31.6 / 33.0 | 33.0 |
| | | 4 | 96.2 | 158.3 | 31.6 / 33.1 | 31.4 / 33.0 | 32.9 |
| | | 5 | 95.6 | 158.0 | 31.2 / 33.0 | 31.2 / 33.0 | 32.8 |
| | | 6 | 95.8 | 158.8 | 31.3 / 33.0 | 31.1 / 33.1 | 32.8 |
| | | 7 | 96.3 | 158.3 | 30.8 / 33.0 | 30.9 / 33.1 | 32.7 |
| | | 8 | 98.7 | 158.6 | 30.9 / 33.0 | 29.9 / 33.0 | 32.6 |
| | | 9 | 103.8 | 158.4 | 28.4 / 33.6 | 27.0 / 33.2 | 32.5 |
| | | 10 | 99.6 | 158.2 | 26.2 / 33.1* | 30.5 / 33.0* | 32.9 |
| Part BJC/4 | Part of fractured link, portside chain | 6 | - | - | 31.6 / 33.2 | - | - |
| Part BJC/5 | Part of portside chain, towards trawl | 7 | 96.6 | 158.2 | 31.3 / 33.0* | 31.4 / 33.0* | 32.8 |
| | | 8 | 99.4 | 158.5 | 31.0 / 32.9 | 28.2 / 33.3 | 32.8 |
| | | 9 | 101.8 | 158.0 | 27.4 / 33.2 | 28.7 / 32.9 | 33.0 |
| | | 10 | 96.7 | 158.8 | 30.2 / 32.9* | 27.9 / 33.1* | 32.9 |

* Link can rotate around neighbouring link, hence crown 1 and crown 2 is chosen arbitrarily.

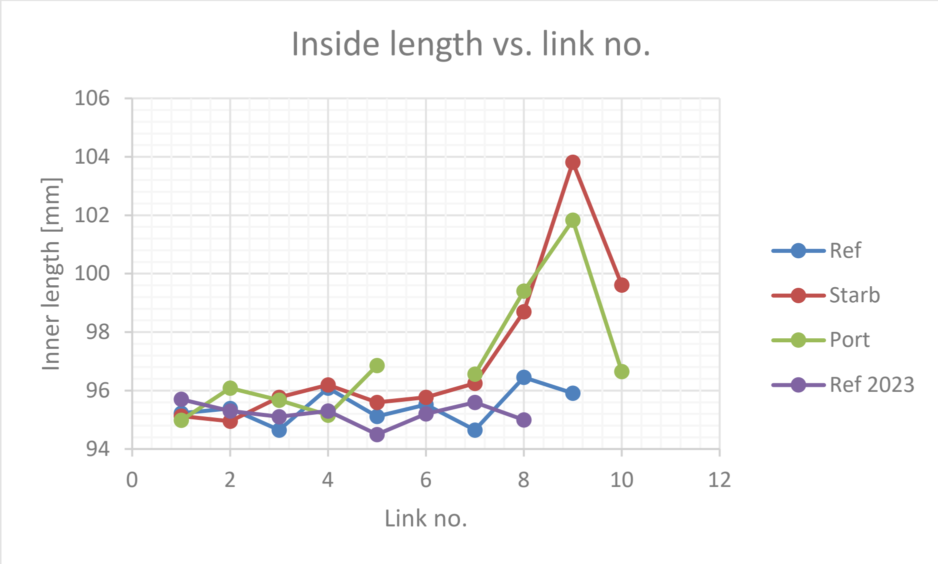


**Figure 3-7 Measured inner length plotted versus link number for all examined chain segments.**

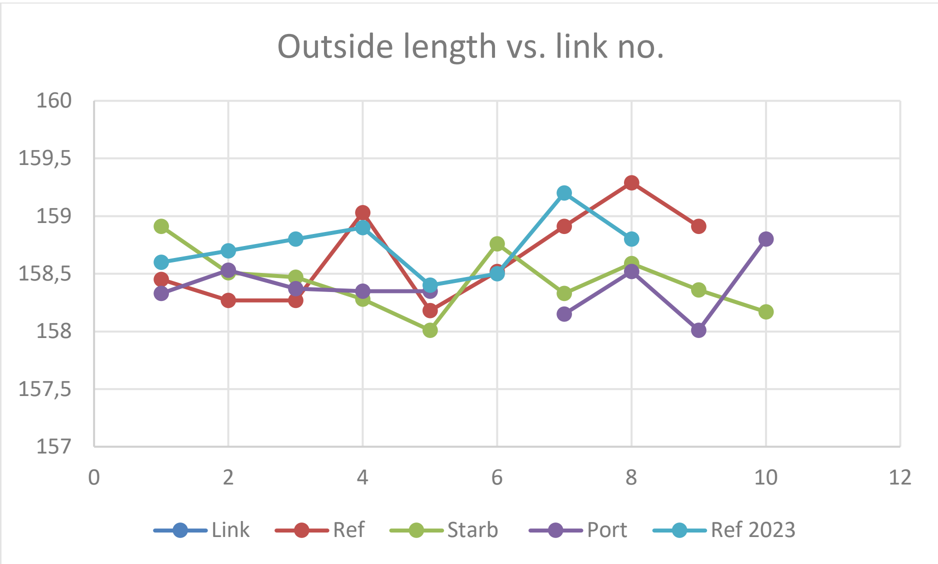


**Figure 3-8 Measured outer length plotted versus link number for all examined chain segments.**

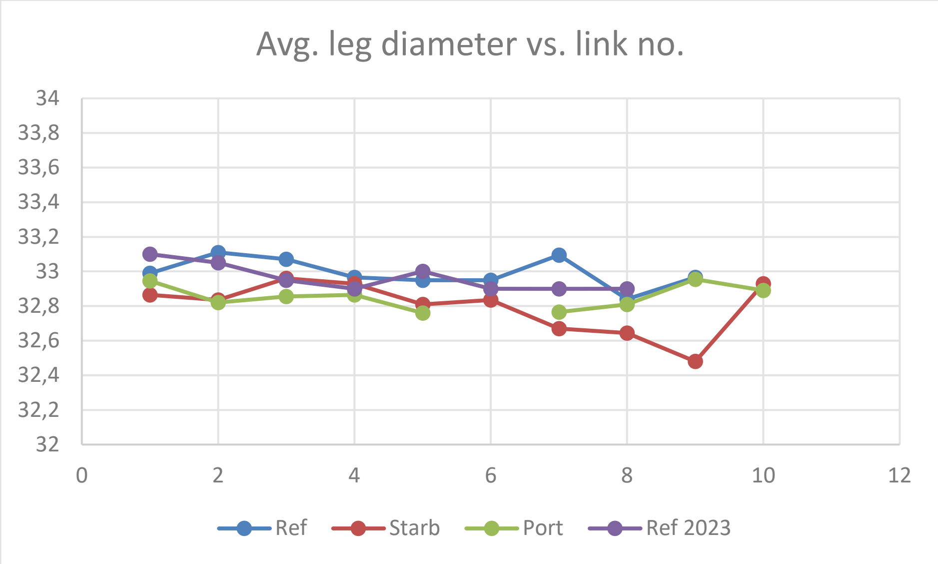


**Figure 3-9 Measured average leg diameter plotted versus link number for all examined chain segments.**

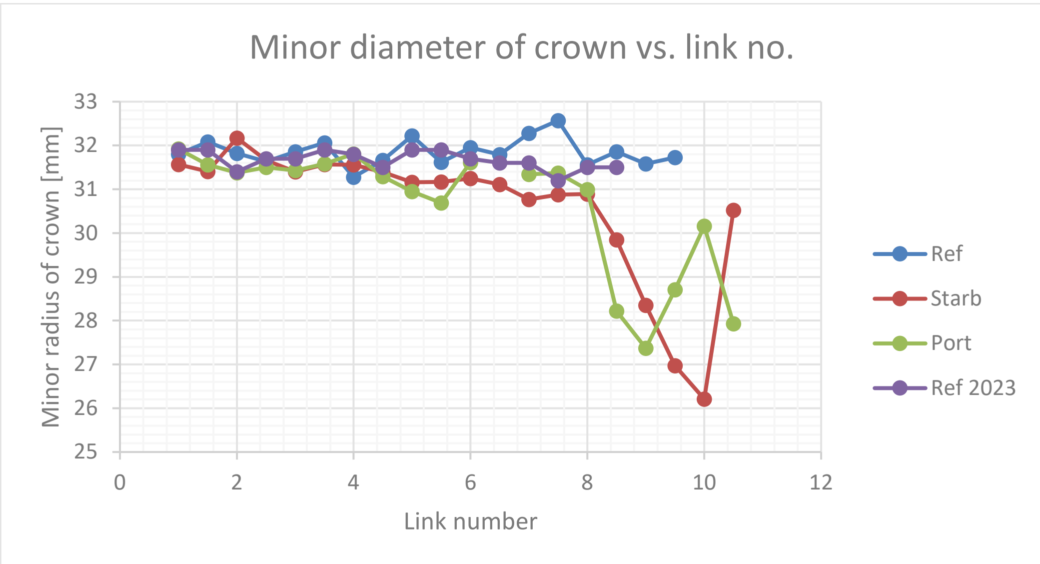


**Figure 3-10 Measured minor crown diameter plotted versus link number for all examined chain segments.**

## 3.6 Chemical analysis

Spectrometric analysis was performed by Degerfors Laboratorium AB on material from link 8. The results are given in Table 3-2 together with relevant requirements. The chemical composition given in the chain certificate and the test results from testing of previous samples are included for comparison. The report from Degerfors Laboratorium AB is enclosed in Appendix D. Note that the manganese content given in the certificate is not correct, ref. documentation included in Appendix E, hence the correct content according to Appendix E is included in Table 3-2. The documentation shows several different analyses referring to the same heat number. All manganese content values are in the range of 1,225 to 1,250 %, hence it is assumed that the value given in the certificate (in Appendix A) is a typo.

The chemical composition of the analysed sample shows good correspondence to the certificate and the results from previous testing. All requirements according to NS-EN ISO 818-2 /2/ and ASTM A391 /3/ are met.

**Table 3-2 Results from chemical analyses.**

| Sample | Chemical composition [wt%] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C | Si | Mn | P | S | Cr | Ni | Mo | Cu | Al |
| MJA/4, link 1 | 0.22 | 0.21 | 1.26 | 0.017 | 0.004 | 0.56 | 0.51 | 0.27 | 0.14 | 0.028 |
| **Certificate** | | | | | | | | | | |
| H52-8 3/19 | 0.211 | 0.216 | 1,225-1,250* | 0.0154 | 0.0064 | 0.567 | 0.510 | - | - | 0.0281 |
| **Requirements according to relevant standards** | | | | | | | | | | |
| NS-EN ISO 818-2 /2/ | | | | Max. 0.025 (cast) / 0.030 (Check) | Max. 0.025 (cast) / 0.030 (Check) | Min. 0.40* | Min. 0.40 | Min. 0.15* | | Min. 0.025 |
| ASTM A391 /3/ | Max. 0.35 | | | Max. 0.025 | Max. 0.025 | Min. 0.40* | Min. 0.40 | Min. 0.15* | | |
| **Results from previous testing /1/** | | | | | | | | | | |
| 1-5 | 0.23 | 0.23 | 1.25 | 0.015 | 0.005 | 0.58 | 0.50 | 0.25 | 0.14 | 0.026 |
| 2-9 | 023 | 0.23 | 1.26 | 0.015 | 0.005 | 0.58 | 0.49 | 0.25 | 0.14 | 0.025 |
| 3-1 | 0.23 | 0.23 | 1.26 | 0.015 | 0.005 | 0.58 | 0.49 | 0.25 | 0.14 | 0.025 |
| 5-10 | 0.24 | 0.23 | 1.25 | 0.015 | 0.005 | 0.58 | 0.49 | 0.25 | 0.14 | 0.026 |
| Fractured link | 0.23 | 0.23 | 1.25 | 0.015 | 0.004 | 0.58 | 0.49 | 0.25 | 0.14 | 0.024 |

* Corrected according to documentation as included in Appendix E.

## 3.7 Tensile testing of chain material

A tensile test specimen (Ø 10 mm) was sectioned in the longitudinal direction of the leg opposite to the weld, from link no. 1.

Testing was performed at room temperature and in accordance with NS-EN ISO 6892-1 /4/. The results from tensile testing are shown in Table 3-3. A stress-strain plot for the test is shown in Figure 3-11. The results are given in Table 3-3, and results from testing of previous samples are included for comparison. The chain certificate does not give results or requirements for tensile testing.

Neither NS-EN ISO 818-2 /2/ nor ASTM A391 /3/ gives relevant requirements, hence, requirements for Grade R6 mooring chain according to DNV-OS-E302 /5/ are included for comparison. Grade R6 is the type of mooring chain with higher strength requirements.

Additional elongation at a shorter gauge length (32 mm (denoted A) instead of 50 mm (denoted $A_5$)) was also calculated for easier comparison to previously tested sample BJC/2.

The results from tensile testing show that both yield strength and tensile strength is lower compared to the previously performed testing. Elongation and contraction are similar to BJC/1 – link 4 from portside chain, however, the elongation (at $L_0$=32 mm) is higher compared to BJC/2, unused reference chain. The yield-to tensile strength ratio is significantly lower compared to the two previous samples, 0.94 compared to 0.99 and 0.998, respectively.

Tensile strength, yield strength and contraction meet requirements for a grad R6 mooring chain according to DNV-OS-E302 /5/, however the elongation is below this requirement.

**Table 3-3 Results from tensile testing.**

| Sample | Sample diameter [mm] | Original gauge length, $L_0$ [mm] | Yield strength, $R_{p0.2}$ [MPa]* | Tensile strength, $R_m$ [MPa] | Elongation $L_0$ = 50 mm [%] | | Elongation $L_0$ = 32 mm [%] | | Contraction | | Fracture |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | $L_U$ [mm] | $A_5$ [%] | $L_U$ [mm] | A [%] | $d_u$ [mm] | Z [%] | |
| MJA/4, link 1 | 10.00 | 50 | 1190 | 1260 | 56.03 | 11.0 | - | 16.5 | - | 59 | Cup and cone |
| **Results from previous testing /1/** | | | | | | | | | | | |
| BJC/1 – link 4 Portside chain | 9.92 | 50 | 1328* | 1341 | 55.67 | 11.5 | 37.36 | 17 | 6.30 | 59 | Cup and cone |
| BJC/2 Unused, ref. chain | 9.94 | 32 | 1403* | 1406 | NA | NA | 36.26 | 13.5 | 6.69 | 56 | Cup and cone |
| **Minimum requirement for mooring chain according to DNV-OS-E302 /5/** | | | | | | | | | | | |
| Grade R6 | - | - | Min. 900 | Min. 1100 | - | Min. 12 | - | - | - | 50 | - |

* Yield strength is determined manually from stress/strain plots as shown in previous report /1/.

Image courtesy of Det Norske Veritas

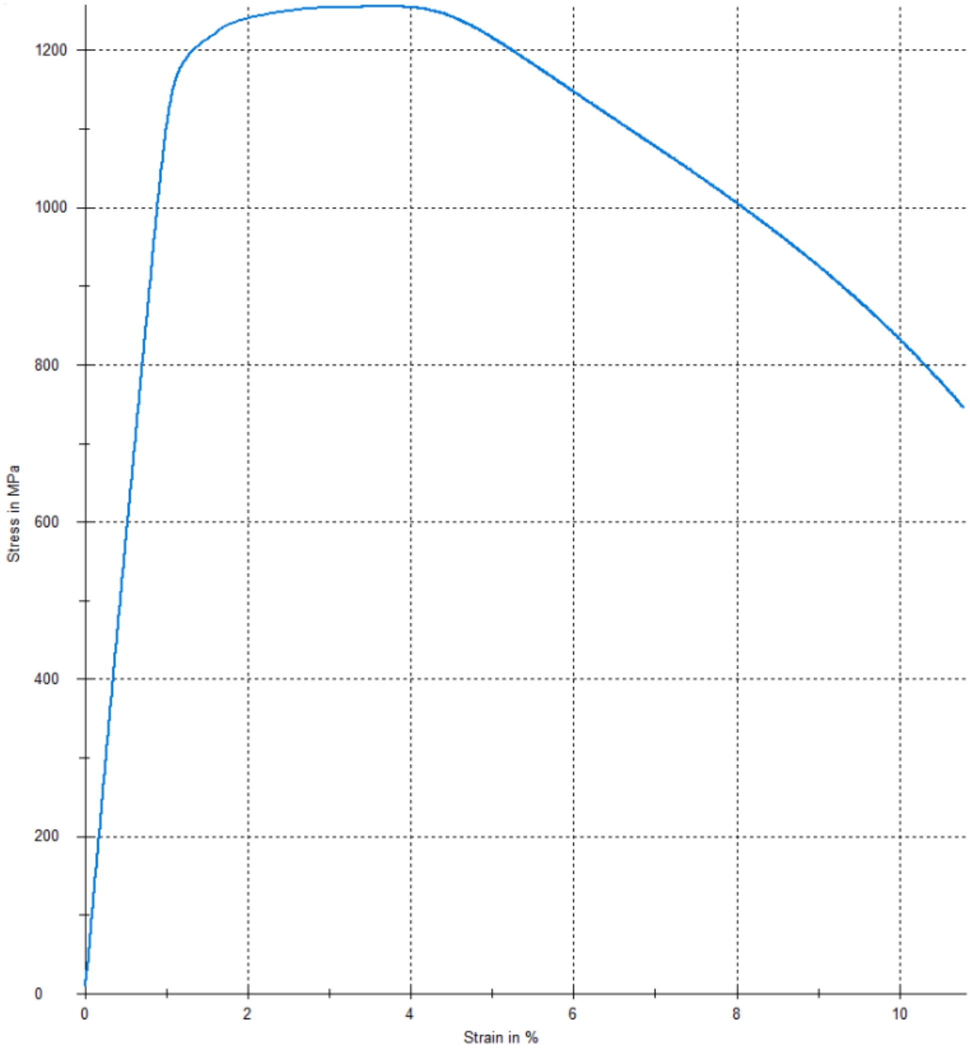


**Figure 3-11 Sample MJA/4, stress-strain plot from tensile testing.**

## 3.8 Hardness testing

On the same cross section as was used for metallographic examination, hardness surveys were performed. A drawing showing the position of the different measurements is shown in Figure 3-12.

Hardness was measured using Vickers hardness method and 10 kg load, according to NS-EN ISO 6507-1 /6/. The average hardness results were converted to estimated tensile strength and Brinell hardness according to NS-EN ISO 18265, Table B.2 /7/. Results from hardness testing of the cross sections are shown in Table 3-4, and results from testing of previous samples are included for comparison. Neither NS-EN ISO 818-2 nor ASTM A391 /2-3/ give any requirements to hardness or tensile strength of the material. NS-EN ISO 818-2 /2/ states that the break load is calculated based on a tensile strength of 800 N/mm$^2$. However, these calculations do not take into account the real geometry of the chain, hence a significantly higher tensile strength is needed to obtain the required break load.

The obtained hardness results are lower compared to the previously performed testing, total average value of 406 HV10 compared to values in the range of 426-431 HV10 in previous testing. The same trend is seen through the survey, a higher hardness is measured in the core compared to the surface for all hardness surveys.

According to a test certificate from the manufacturer, forwarded by the client (given in Appendix B), the expected hardness is 375 HB, corresponding to 380 HV10, according to NS-EN ISO 18265 /7/. Brinell hardness cannot be compared directly to Vickers hardness, however an estimated converted value for Vickers hardness is found, using NS-EN ISO 18265 /7/. The obtained results are significantly above this value.

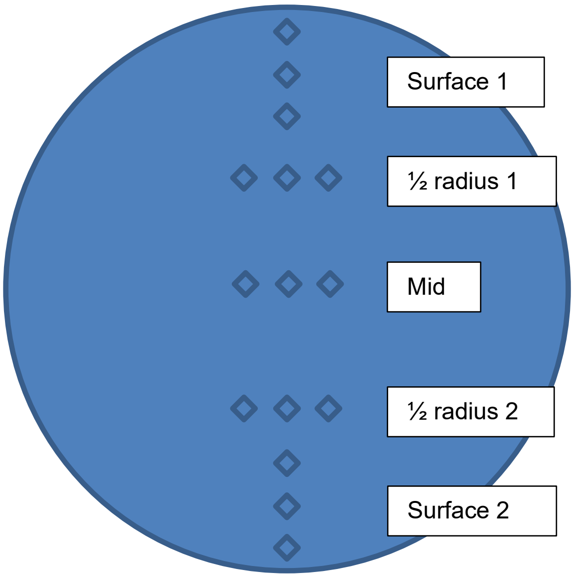


**Figure 3-12 Drawing showing the schematic position of the hardness measurements. Note that the drawing is not to scale. The distance between the measurements in each group is 1 mm.**

**Table 3-4 Results from hardness testing.**

| | Measured hardness [HV10] | | | | |
|---|---|---|---|---|---|
| | Surface 1 [HV10] | ½ radius 1 [HV10] | Mid [HV10] | ½ radius 2 [HV10] | Surface 2 [HV10] |
| MJA/4, link 1, Reference 2023 | 392<br>395<br>392 | 408-415-412 | 402-404-414 | 407-417-413 | 410<br>402<br>404 |
| **Test certificate from manufacturer** | | | | | |
| H52-8 3/19 | - | - | - | - | - |
| **Results from previous testing /1/** | | | | | |
| Link 1-5, Portside chain | 415<br>421<br>426 | 435-437-438 | 522*-438-419 | 424-415-411 | 420<br>420<br>417 |
| Link 2-9, Unused reference | 419<br>418<br>422 | 443-443-431 | 423-420-394 | 443-448-449 | 434<br>432<br>429 |
| Link 3-1, Starboard chain | 424<br>422<br>425 | 410-419-413 | 448-420-459 | 451-452-449 | 431<br>426<br>420 |
| Link 5-10, Portside chain | 424<br>428<br>438 | 444-445-448 | 420-401-416 | 443-444-447 | 409<br>409<br>420 |
| Fractured, Portside chain | 417<br>425<br>422 | 436-434-434 | 420-417-417 | 429-437-433 | 421<br>428<br>421 |
| | | | | | |
| | **Average, surface [HV10]** | **Average, core [HV10]** | **Total average [HV10]** | **Tensile strength [MPa]** | **Brinell hardness [HB]** |
| Part MJA/4, link 1, Reference 2023 | 399 | 410 | 406 | 1269 | 401 |
| **Test certificate from manufacturer** | | | | | |
| H52-8 3/19 | - | - | - | - | 373 |
| **Results from previous testing /1/** | | | | | |
| Link 1-5, Portside chain | 420 | 438 | 431 | 1344 | 425 |
| Link 2-9, Unused reference | 426 | 433 | 430 | 1341 | 424 |
| Link 3-1, Starboard chain | 425 | 436 | 431 | 1344 | 425 |
| Link 5-10, Portside chain | 421 | 434 | 429 | 1338 | 423 |
| Fractured, Portside chain | 422 | 429 | 426 | 1329 | 420 |

* This value is most likely a typing error; the correct value should most likely be 422 HV10. It is not corrected in the reported results, average values or converted tensile strength and Brinell hardness.

## 3.9 Metallographic examination

The cut cross section was prepared by standard metallographic methods and etched using 2% Nital (nitric acid in ethanol) to reveal the microstructure.

The examined cross section had a quenched and tempered microstructure, as expected. This is also as specified both in NS-EN ISO 818-2 and ASTM A391 /2-3/. No significant differences are observed between different areas of the cross section. Also, no significant difference was observed between the examined link and the links from chain segments examined previously /1/.

A typical example of the microstructure is shown in Figure 3-13. Figure 3-14 shows a representative microstructure from the fractured chain link from the previous examination.

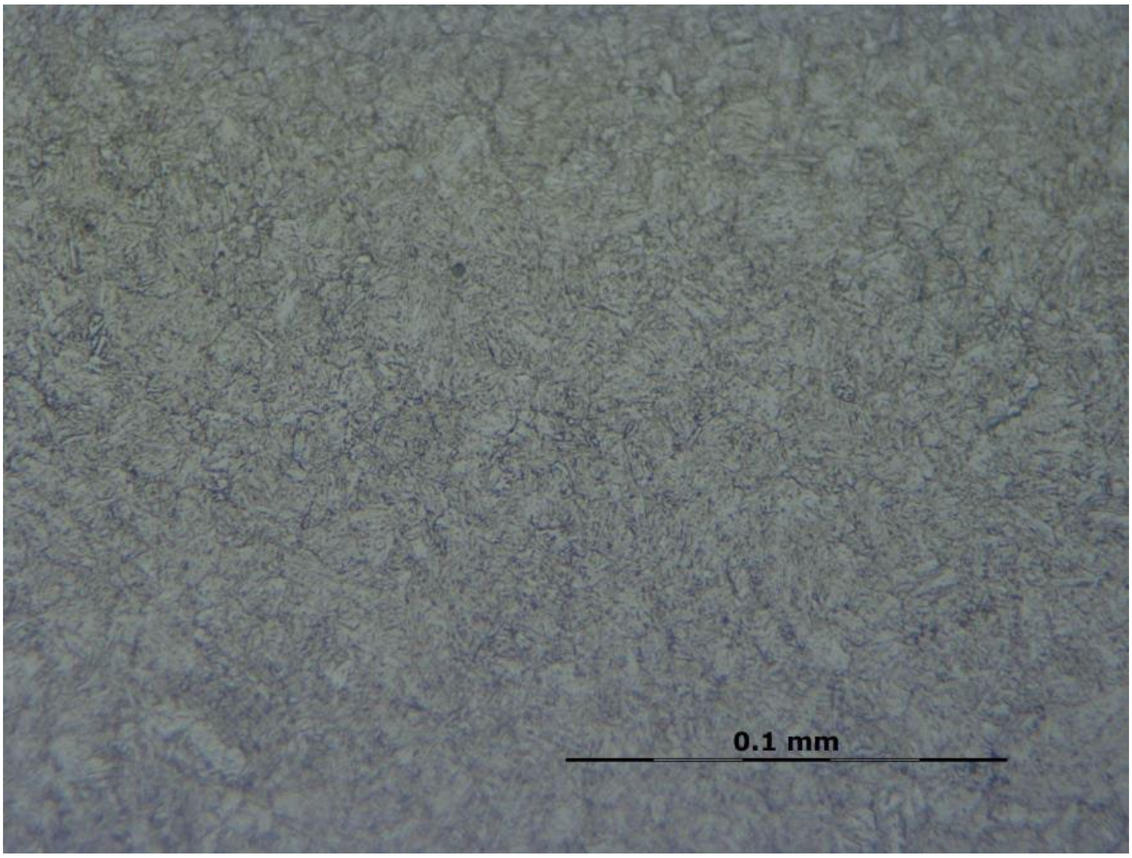


**Figure 3-13 MJA/4, link 1. Representative quenched and tempered microstructure.**

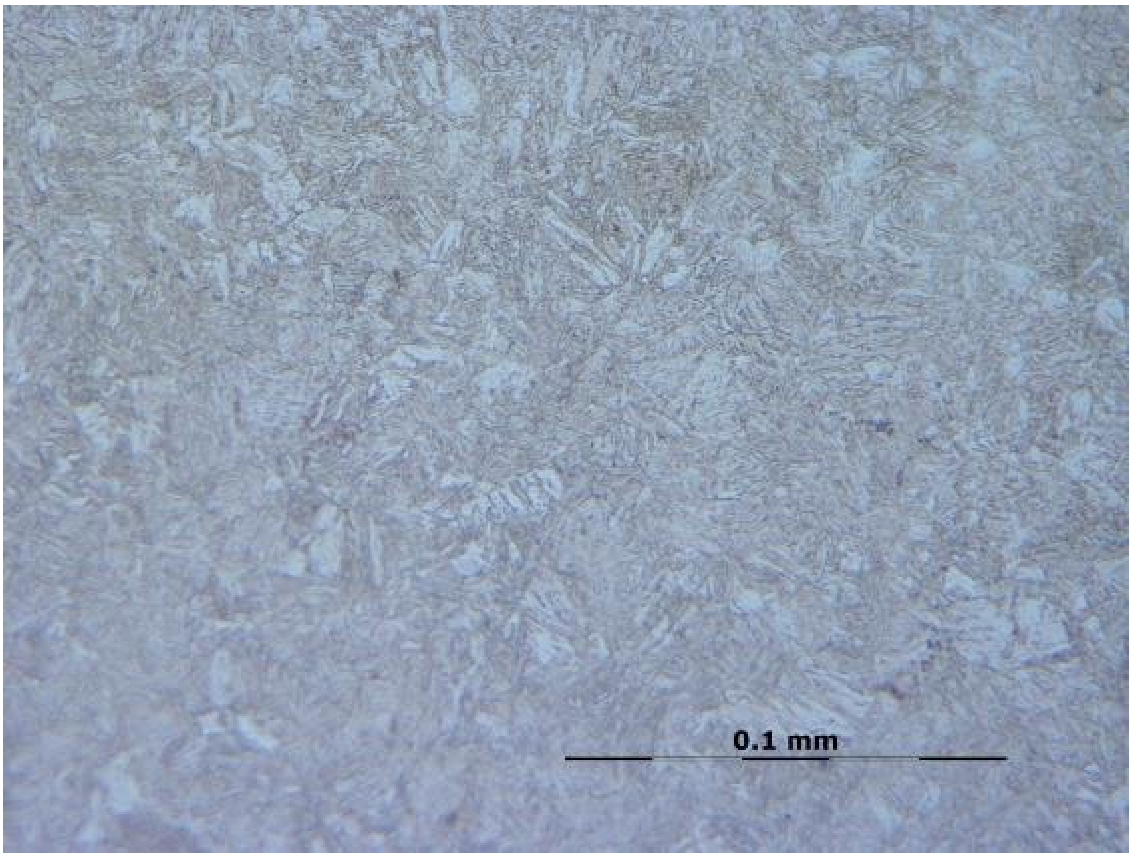


**Figure 3-14 Sample BJC/4 (Fractured link). Representative quenched and tempered microstructure.**

## 3.10 Break load testing

### 3.10.1 Test machine

The testing was performed at DNV GL's "Technology Centre for Offshore Mooring and Lifting" in Bergen, Norway, utilizing the 3,200 kN tensile capacity (designated "Ormen Lange") test machine. The tensile testing machine operate with one fixed crosshead and one moving crosshead. The static end is connected to a hydraulic cylinder that can shift the test set-up with increments without unloading the test object (during the testing the static end is fixated by pins). This is necessary if the test specimen elongates more than the total stroke of length of the active cylinder. A picture of the 3,200 kN capacity machine is shown in Figure 3-15.

The machine is operated with an integrated controller and data acquisition system and calibrated to Class 1 accuracy. The Certificate of Calibration is enclosed in Appendix F.

**Figure 3-15 3,200 kN tensile capacity (designated "Ormen Lange") test machine. Note that the machine has been relocated after the image was taken.**

### 3.10.2 Test procedure

The chain segments were loaded at a loading rate of 15 mm/minute from the start. As the chain segment started yielding, the loading rate was gradually increased to maintain a constant load per time rate (kN/min).

### 3.10.3 Test results

The obtained breaking load and location of failure is presented in Table 3-5, together with results from previous testing /1/. The obtained break load is below the requirement for a Ø32 mm Grad 8 chain according to NS-EN ISO 818-2 and

ASTM A391 /2-3/ and quite close to the obtained break load for Part BJC/2, unused reference chain tested previously /1/.

**Table 3-5 Obtained breaking loads and location of fracture.**

| Test id.: | Obtained breaking load | Location of fracture |
|---|---|---|
| Part MJA/4 - Ref 2023 (link 2-8) | 1011 | Crown of middle link |
| **Requirements according to relevant standards** | | |
| NS-EN ISO 818-2 /2/ | 1290 kN | - |
| ASTM A391 /3/ | 1288 kN | - |
| **Certificate** | | |
| **Result** | 1480 kN | - |
| **Requirement** | 1290 kN | - |
| **Results from previous testing /1/** | | |
| Part BJC/3, starboard used chain (including several links with crack-like indications) | 223 kN | Three fractures of link 4, all in cracks formed in service |
| Part BJC/2, unused reference | 994 kN | Crown of middle link |

The tension vs. total elongation graph is presented in Figure 3-16 .

Overview images showing the fractured chain after testing is shown in Figure 3-17. The fracture surfaces were cut off for further examination.

Compared to the previous testing, the position of the fracture, the break load and the overview of the fracture appears similar to what was obtained for Part BJC/2, unused reference chain. Images showing this are presented in Figure 3-17 and Figure 3-18.

Image courtesy of Det Norske Veritas

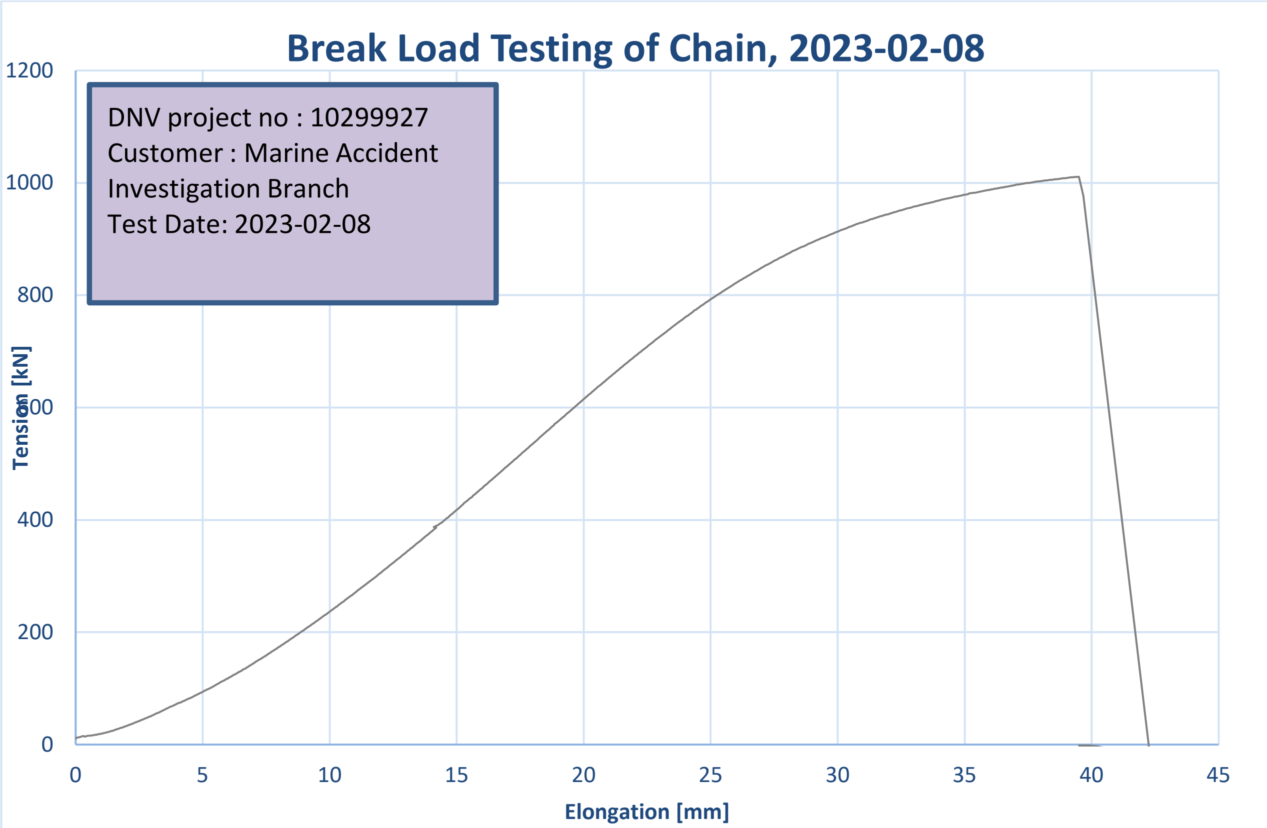


**Figure 3-16 Part MJA/4: Tension versus total elongation for break load testing.**


**Figure 3-17 Part MJA/4: Sample after break load testing.**

**Figure 3-18 Part BJC/2: Sample after break load testing.**

## 3.11 Fractographic examination of sample from break load testing

Overview images showing the two fracture surfaces from break load testing are presented in Figure 3-19. Parts of the fracture surfaces are deformed as the neighbouring chain link was pulled through the opening, seen as shiny areas in Figure 3-19. Fracture surface B was chosen for further examination due to less post-fracture deformation.


**Figure 3-19 Part MJA/4: Overview images showing the fracture surfaces from break load testing. The inner part of the crown (intrados) is shown downwards.**

Fracture surface B has two main areas, separated by a deformed area across the mid-height of the surface. Typical low magnification fracture topography of the two different areas is shown in Figure 3-20 and Figure 3-21. The inner part of the fracture surface has a rougher appearance compared to the outer part. Somewhat above (outside) of the deformed area, a stripe pattern is observed, as shown in Figure 3-22.

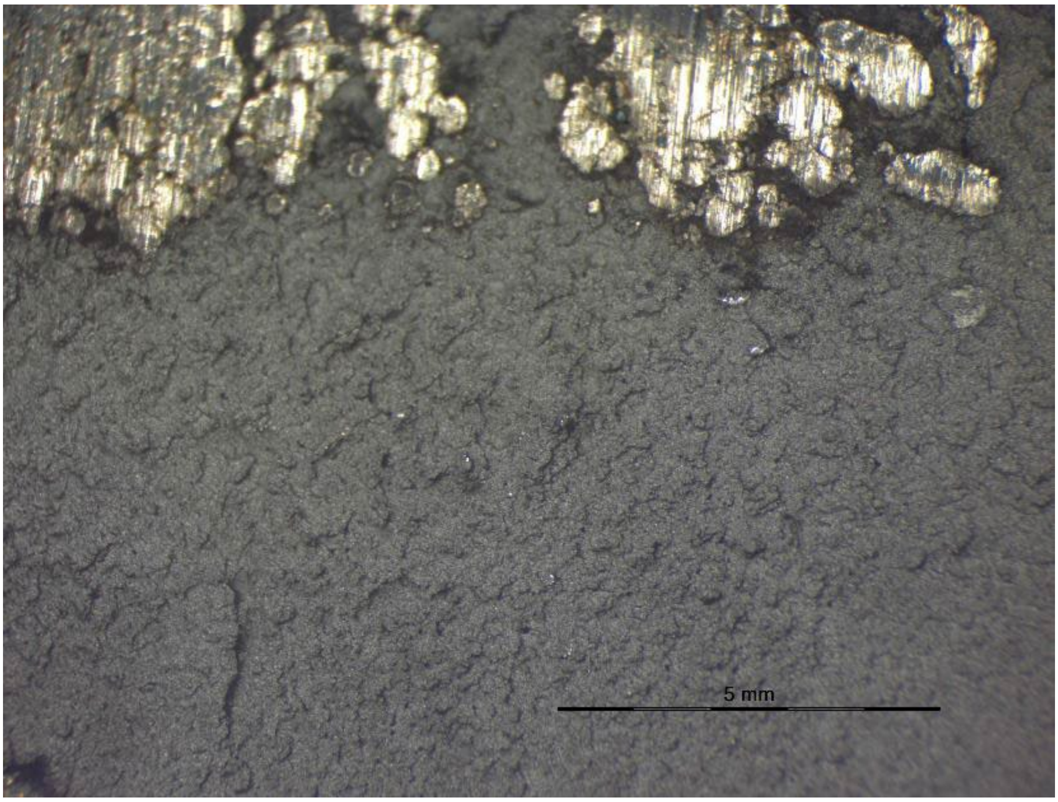


**Figure 3-20 Part MJA/4: Typical appearance of the inner (lower) part of fracture surface B from break load testing.**

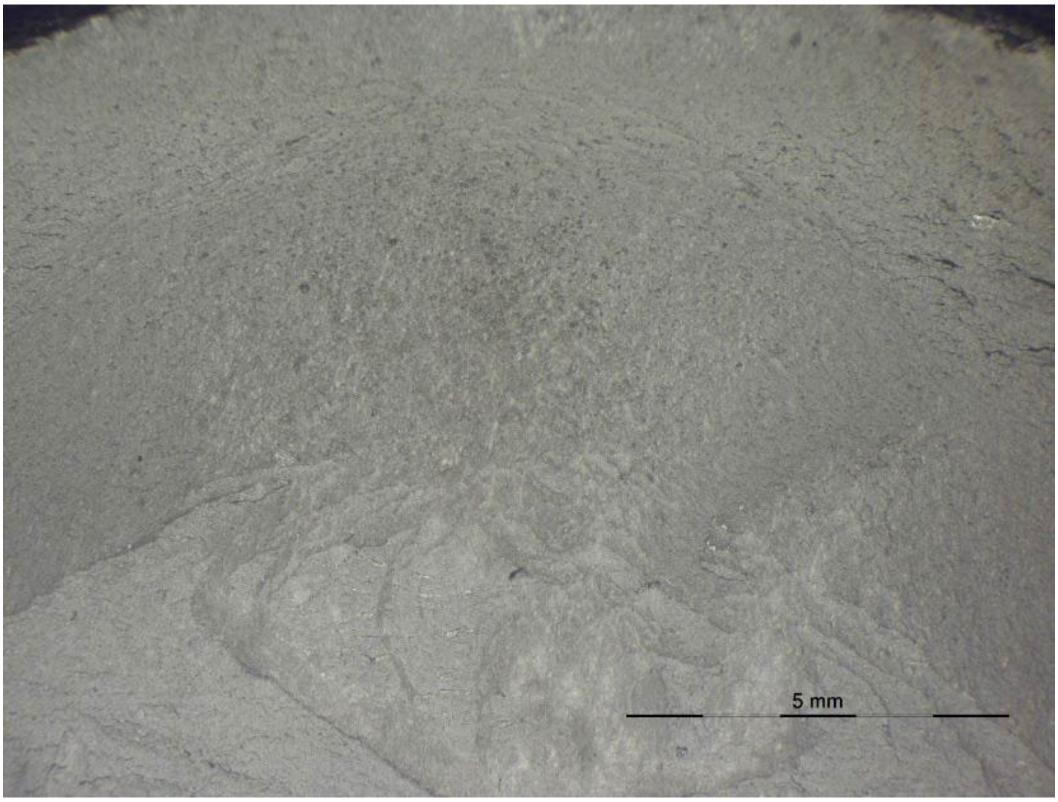


**Figure 3-21 Part MJA/4: Typical appearance of the outer (upper) part of fracture surface B from break load testing.**

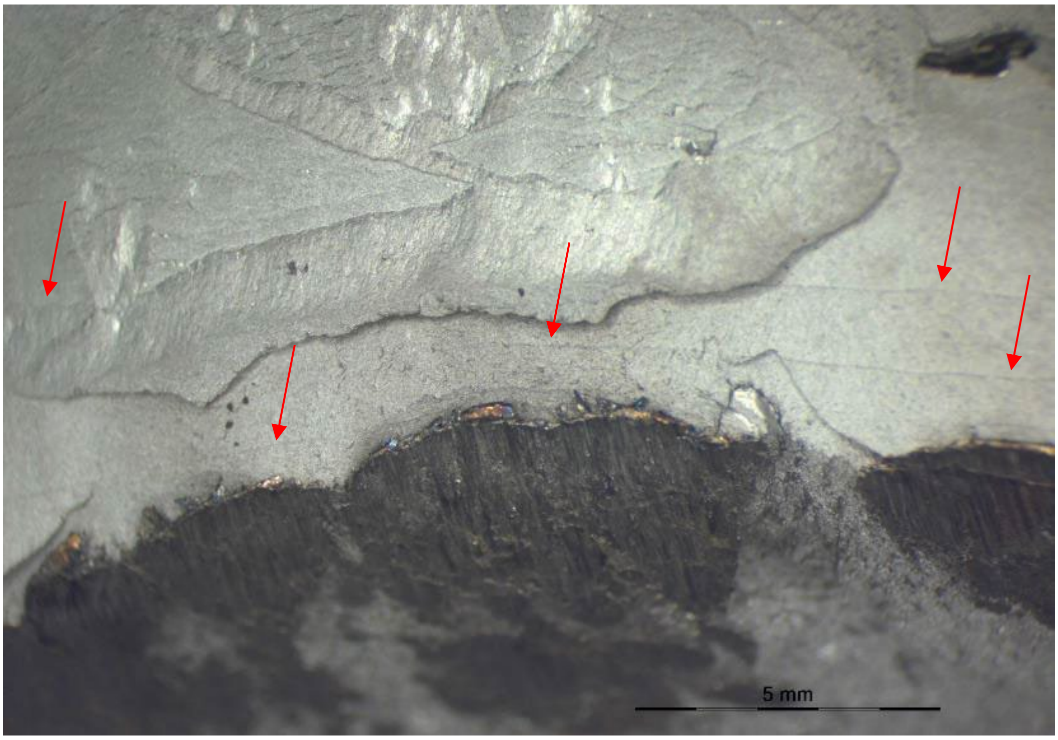


**Figure 3-22 Part MJA/4: Stripe pattern observed in the mid part of fracture surface B from break load testing.**

Fracture surface B was further examined using a scanning electron microscope, giving higher magnification and larger depth of field. An overview image showing the position of the close-up images are given in Figure 3-23.

Figure 3-24 shows the stripe pattern observed at lower magnification, see Figure 3-22. The high magnification images shows that the stripes are not cracks, only unevenness in the fracture surface, most likely formed due to propagation of the crack front.

Images from the outer (upper) part of the fracture surface are given in Figure 3-25 and Figure 3-26. Figure 3-25 shows a dimple topography typical for ductile overload in the mid of the upper area. Figure 3-26 shows a mixture of ductile and brittle area a bit to the side of the fracture surface.

Images from the inner (lower) part of the fracture surface are given in Figure 3-27 to Figure 3-30. The fracture surface has a mainly brittle appearance, with a large portion of cleavage fracture, however areas of dimple topography is seen in between the more brittle areas.

The fractographic examination shows that all examined areas have overload fracture, as expected from a break load test. The areas where dimple topography is seen, the material has behaved ductile when loaded, while the material where cleavage fracture topography and intergranular (i.e., fracture following the grain boundaries) fracture topography is seen, the material has fractured in a brittle manner.

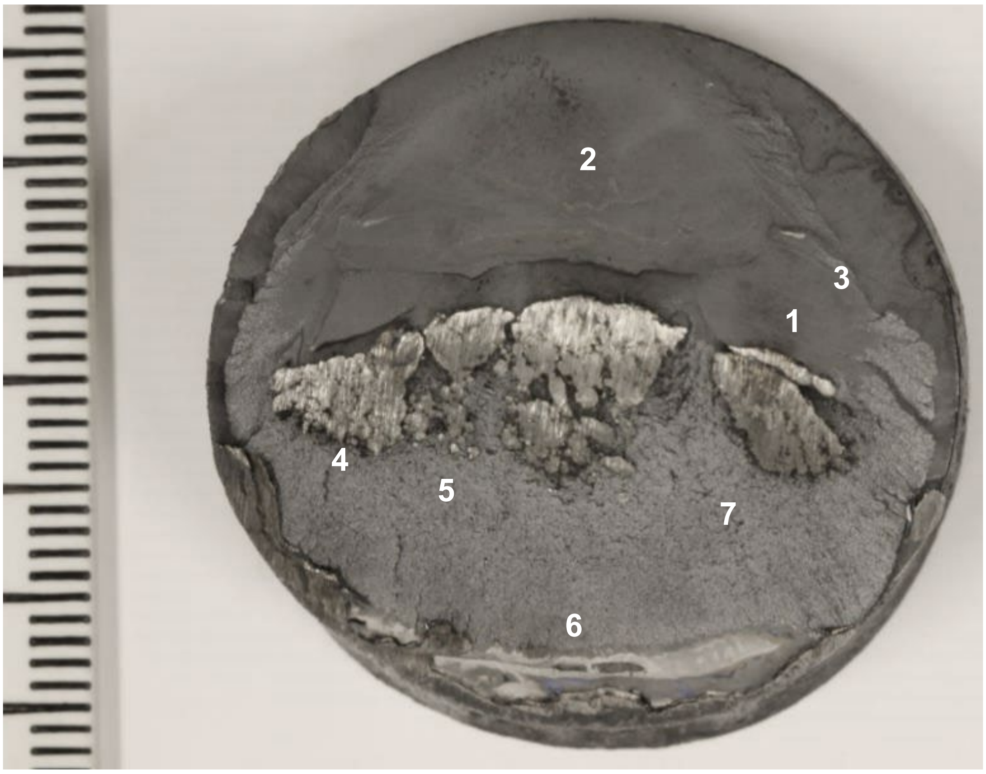


**Figure 3-23 Part MJA/4: Overview image showing the approximate position of SEM images.**

Image courtesy of Det Norske Veritas



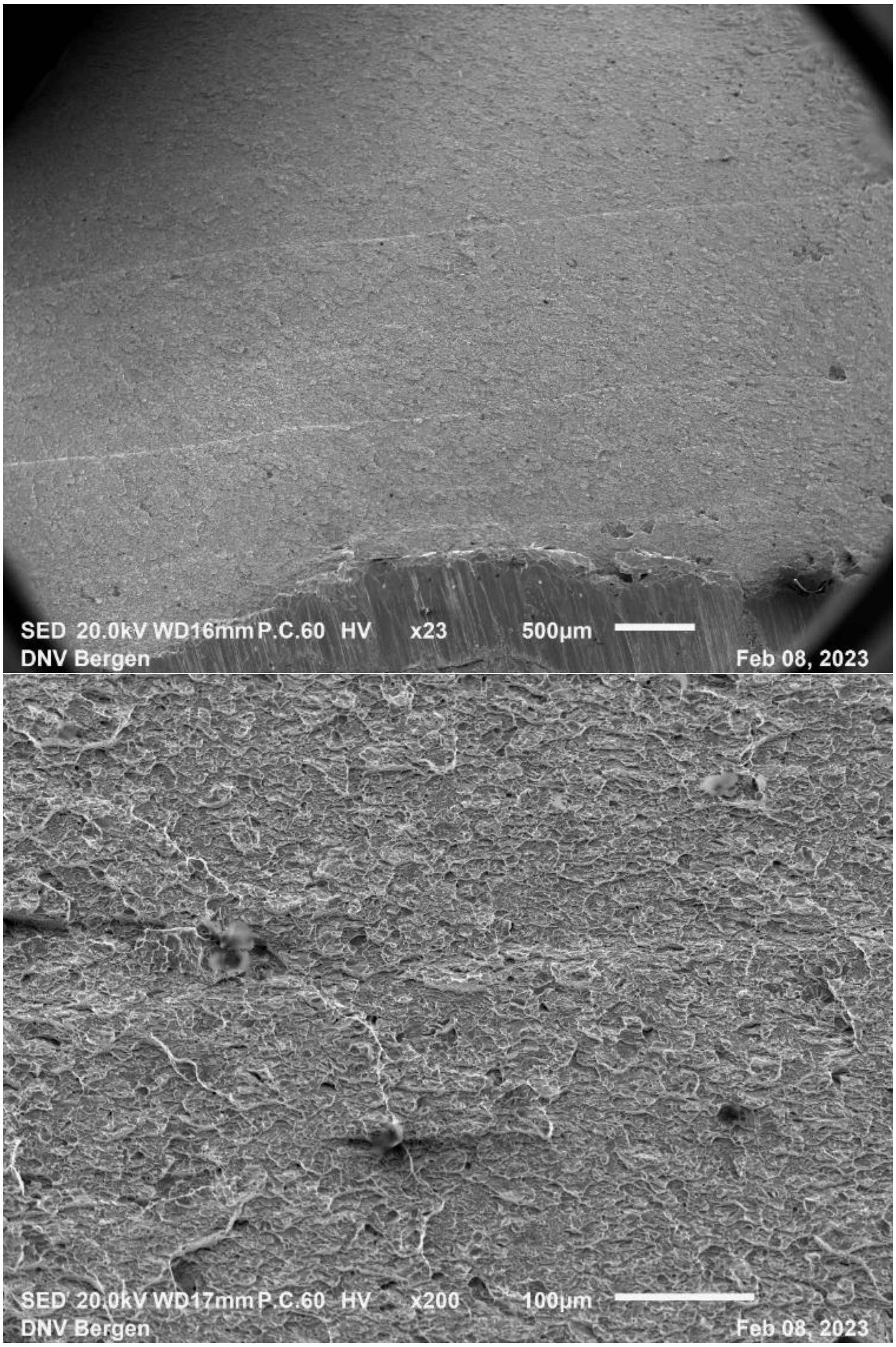


**Figure 3-24 Part MJA/4, area 1: Observed stripe pattern does not indicate cracks, however only unevenness in fracture surface.**

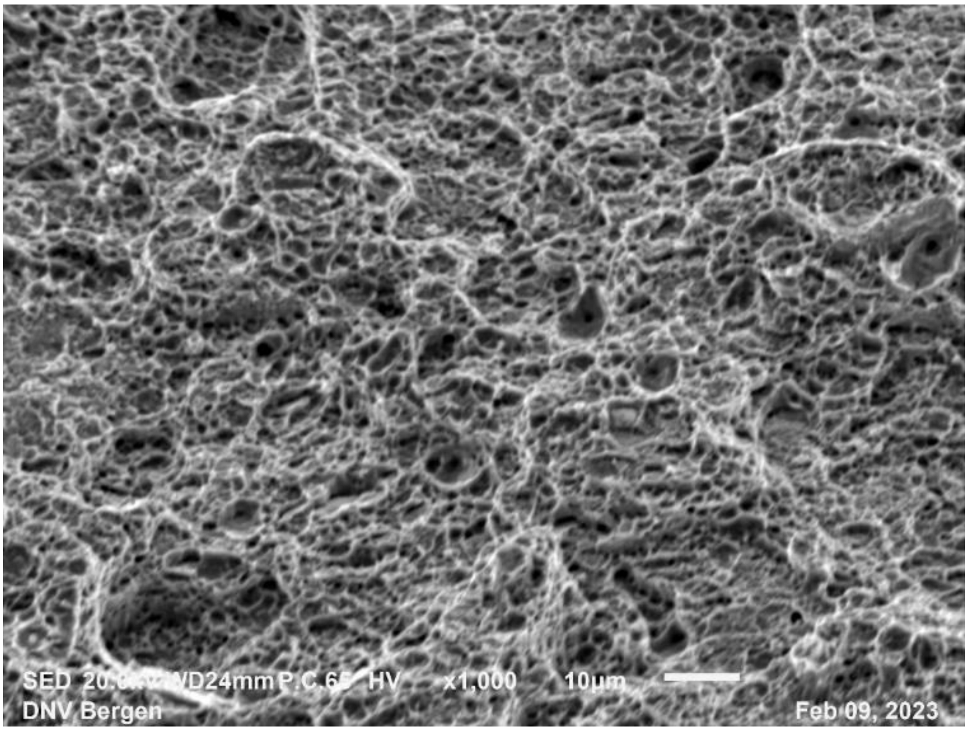


**Figure 3-25 Part MJA/4, area 2: Dimple topography typical for ductile overload, in the middle of the upper area.**

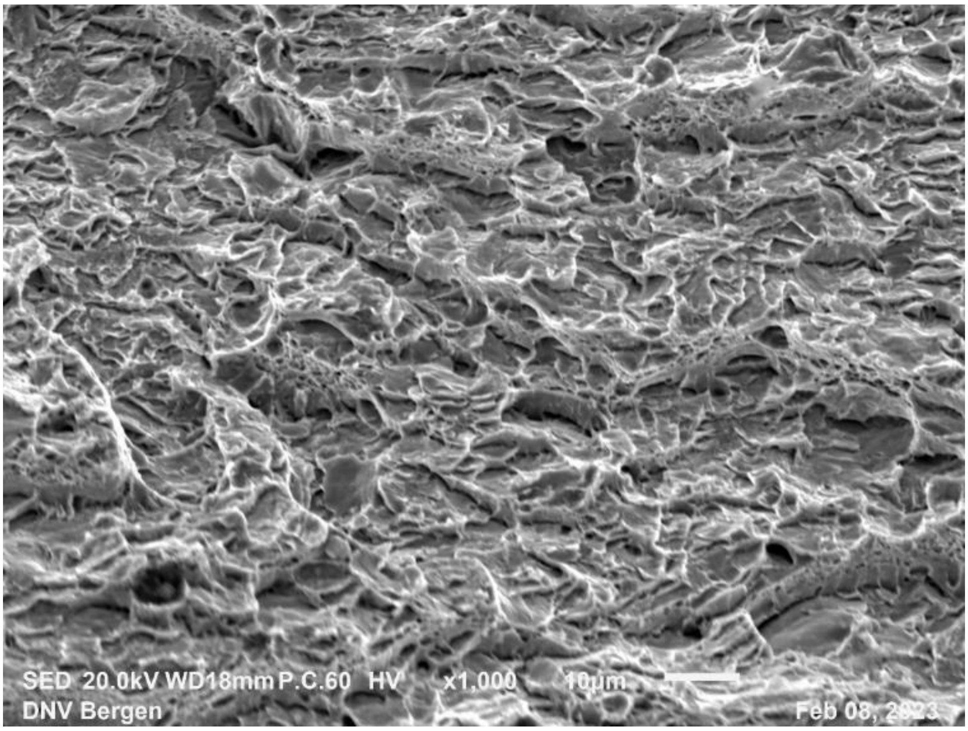


**Figure 3-26 Part MJA/4, area 3: Mixture of dimple topography and cleavage fracture.**

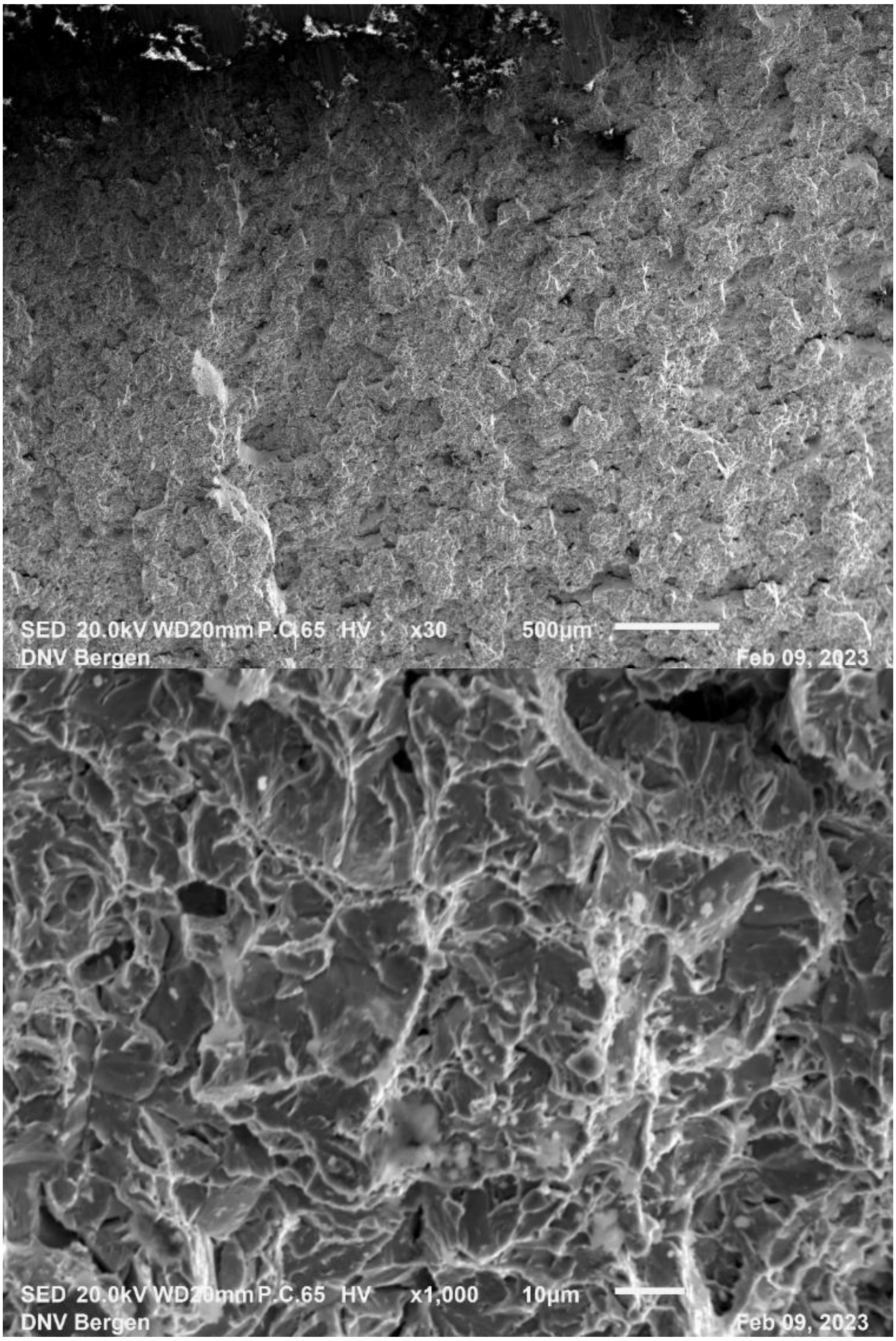


**Figure 3-27 Part MJA/4, area 4: Mixture of intergranular cracking and cleavage fracture.**

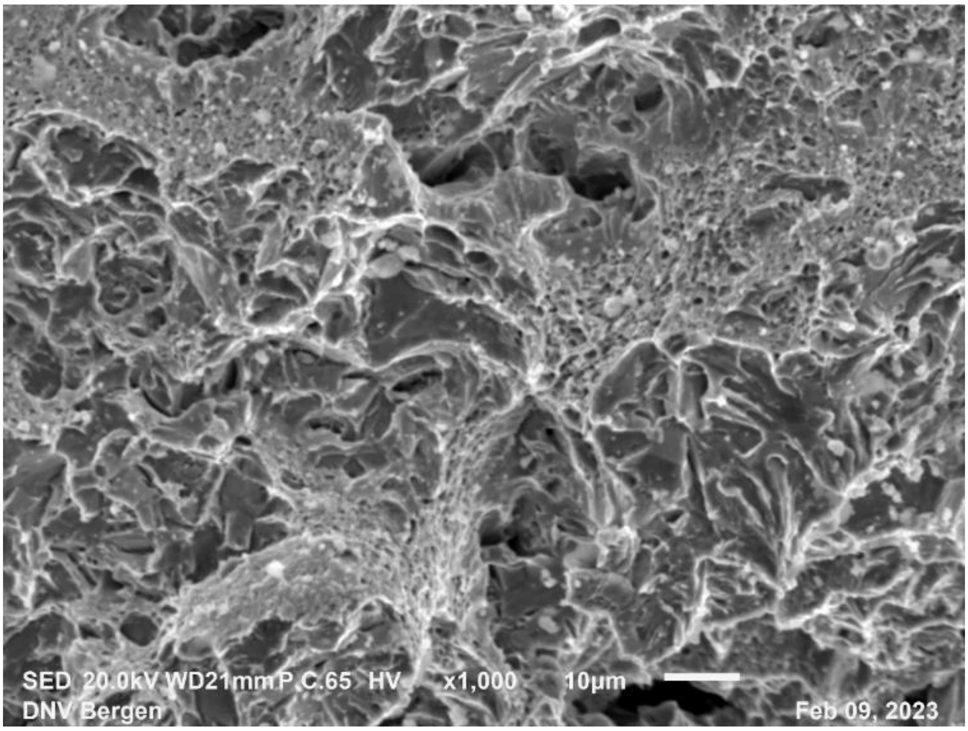


**Figure 3-28 Part MJA/4, area 5: Mixture of dimple topography and cleavage fracture.**

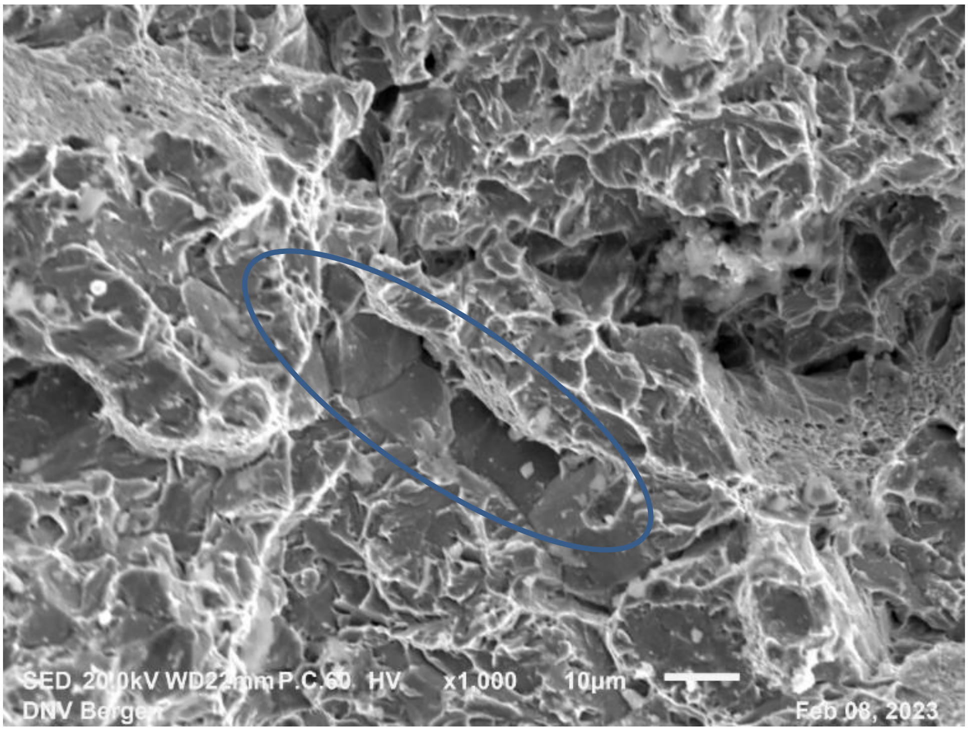


**Figure 3-29 Part MJA/4, area 6: Mixture of intergranular cracking (encircled area), cleavage fracture and dimple topography.**

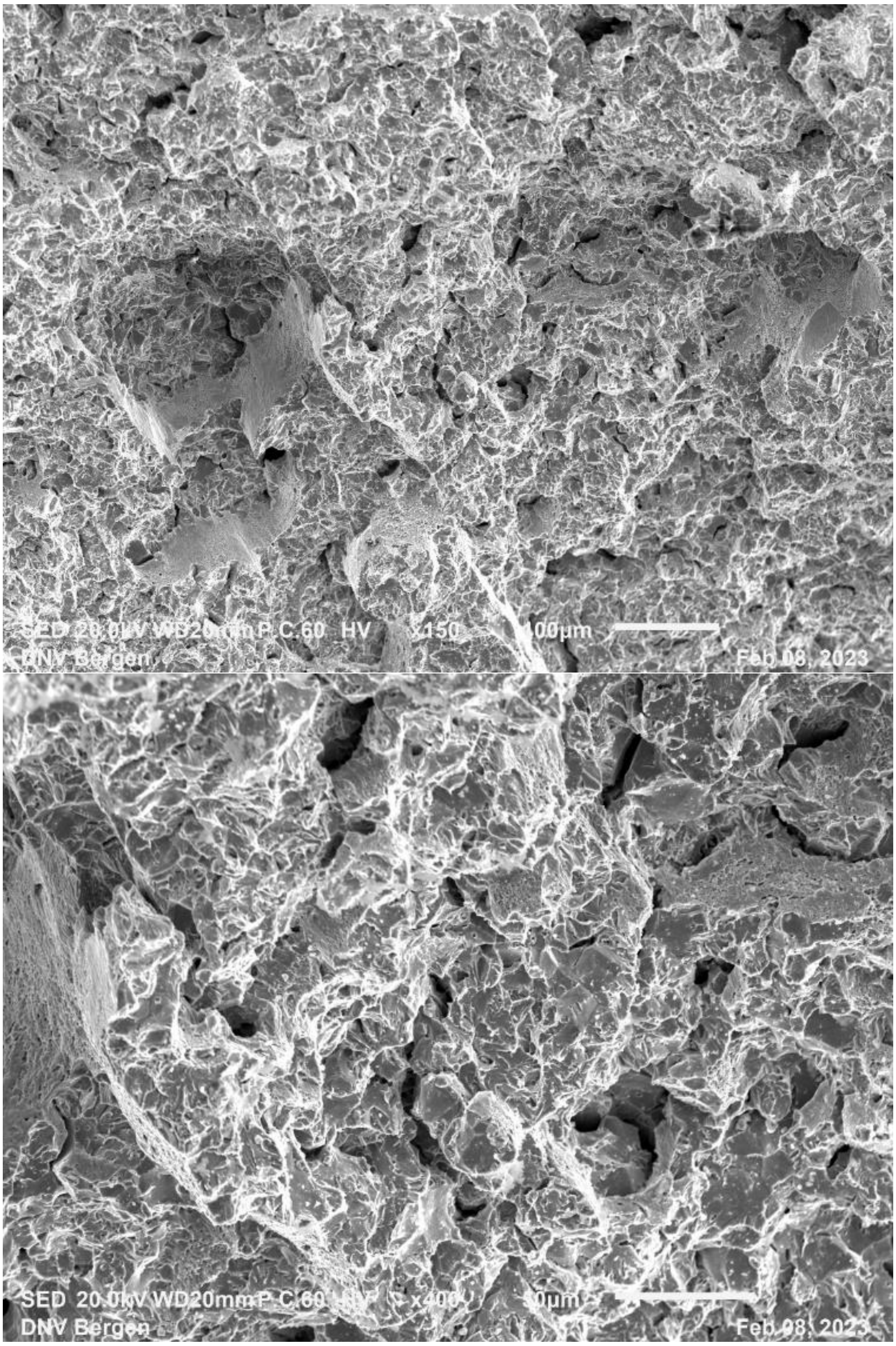


**Figure 3-30 Part MJA/4, area 7: Mixture of intergranular cracking and cleavage fracture.**

# 4 DISCUSSION

## 4.1 Summary

Based on the performed examination of chain sample MJA/4, the following is summarised:

- No indications were reported from fluorescent MPI.
- Visual examination of the chain samples has shown no apparent damage to the chain, and the measured dimensions meet requirements and correspond to previously tested chain samples /1/.
- Tensile testing showed results somewhat lower compared to previously tested chain samples /1/, and with a lower yield-to-tensile strength ratio.
- Hardness testing has shown hardness results somewhat higher than results reported from the manufacturer (Appendix B) and somewhat lower compared to previously tested chain samples /1/. Tensile strength converted from hardness measurements shows good correspondence with the actual tensile testing.
- The chemical composition corresponds to the certificate and results from previously tested chain samples /1/. Regarding manganese content given in the certificate, this is assumed to be a typo, ref. Appendix E.
- The actual break load shows good correspondence to previous testing /1/, however, is significantly lower compared to the value given in the certificate, and requirements given in the relevant standards /2-3/.
- Fractographic examination of sample from break load testing shows brittle fracture topography in the inner part of the fracture surface, with areas of intergranular crack propagation.

## 4.2 Traceability to certificate

The marking of the two reference chains (MJA/4 and BJC/2) is the same and the same as is stated in the certificate. The chemical composition of the two reference chain samples and the other parts from the used chain all correspond to each other and to the certificate. The visual appearance and dimensions for all examined chain lengths are similar and meet given requirements.

The mechanical properties on the other hand do not correspond to the certificate. The measured hardness is higher compared to the test certificate and the break load is 67-68% of the certificate value.

Large variation in mechanical properties for material with similar chemical composition, is most likely due to variation in heat treatment. Large variation can be seen without a clear indication in the microstructure. No information regarding heat treatment is given in the certificate. NS-EN ISO 818-2 /2/ gives some minimum requirements to the heat treatment process, however, does not describe a specific procedure. If heat treatment is performed in batches, there can potentially be differences between different batches, or within a single batch (due to placement in furnace combined with temperature gradients, for instance). For a continuous heat treatment, there can potentially be differences between different parts of the chain due to both planned and unplanned start and stops.

According to NS-EN ISO 818-2, the size of a lot is supposed to be 200 m, and according to ASTM A391 /3/, a lot can comprise 1000 m chain, however the number of test samples is higher for one lot according to ASTM A391 /3/. A lot is, according to the standards, a unit for which the number of mechanical tests is specified. The certificate describes 2 strands of 50 m (assumed two lengths of 50 m); however, it is not clear if this is the whole lot or refers to the purchase of the described amount of chain.

## 4.3 Assessment of actual break load

The actual break load of the tested chain (MJA/4) is significantly lower compared to the requirements according to the certificate, the results presented in the certificate and the requirements given in standards that the certificate refers to /2-3/, however corresponds well to the reference chain (sample BJC/2) tested in 2021 /1/. Low actual break load of the chain is not expected based on the high hardness and tensile strength of the base material (tensile strength and hardness are more or less proportional properties), hence other factors are believed to explain the low break load, not a low tensile strength.

It must be emphasised that, as discussed in the previous report /1/, the low actual break load is not considered a direct cause of the failure of the chain onboard the trawler Cornishman. For the current use and typical loads, it is not considered likely that the chain would have fractured in pure tensile overload, ref. the starboard chain that has been in use with a through-thickness crack. However, for a higher utilization of the chain, this could have serious negative effects in the form of premature fracture, as seen in the break load testing.

The main differences between break load testing of the chain and standard tensile testing of the base material are the position of the fractured material and the loading mode. The break load test considers the full cross section including any surface effects while the tensile test is machined from material within the chain link. Hence, tensile test samples will not be influenced by surface effects. The fractured area of the tensile testing is close to the mid length of the leg without weld, and approximately in the middle part of the material (diameter of sample is 10 mm, compared to a 32 mm diameter of the length), while for both the break load tests, the chain fractured in the middle of the crown. Tensile test samples have a close to homogeneous tensile stress throughout the complete cross section, while for break load the fractured area will experience a decrease from maximum tensile stress on the outer part of the crown cross section.

A short assessment of various factors that can have contributed to the low actual break load:

- Pre-existing cracks:

  For both the samples with low actual break load, visual examination and fluorescent MPI was performed prior to testing, without any indications detected. However, the chain samples are coated, hence some obscuring of surface cracks can be possible, and also non-surface breaking cracks can be present. The fracture surfaces of the two break load samples were examined after testing; however, the relevant area is deformed from the neighboring link slipping through the cracked link, hence examination after testing cannot give any indication of possible pre-testing cracks. The break load test will be affected by surface defects, while tensile testing will not be affected by surface defects as these have been removed through machining. It is not believed that the low break load is related to significant cracks in the chain links, however, it cannot be concluded or excluded if small pre-existing cracks in the crown area can be a contributing cause for the low actual break load.

- Geometry:

  For both the samples with low actual break load, dimension measurements were made prior to testing. The crown diameters in two perpendicular directions were determined and compared to other links, as shown in Paragraph 3.5. All diameter measurements are within the requirements stated in the certificate and according to the relevant standards /2-3/. There is no reason to believe that the geometry of the chain links is a direct or contributing cause for the low actual break load.

- Related to ductility:

  Previous tensile tests have shown a very high yield strength to tensile strength ratio, 0.998 and 0.99 /1/. In the current test, a yield to tensile strength ratio of 0.94 was achieved, which is more as expected for the material. Some variation in elongation is also seen between the different samples. The low actual break load could be related to the high yield to tensile strength ratio; however it is then not clear why the current sample, with yield to tensile strength ratio of 0.94, have a similar actual break load as the previously tested reference chain, with yield to tensile strength ratio of 0.998. It cannot be excluded that there are large local differences between the chain link that fractured in break load testing and the link used for tensile testing.

- Residual stresses in chain link:

  During cutting of chain links for characterization of chain link material, it was noted compressive residual stresses, as the saw blade got caught in the chain link as soon as the link was cut through. The residual stresses are likely to be formed during production (forming), however has not been released during heat treatment. When compressive stresses are found on some part of the chain, it is likely to have tensile residual stresses in other parts of the chain. The residual stresses will, when not released prior to testing, influence break load, by adding to (positively or negatively) the stresses inflicted on the chain from the tensile test machine. For the tensile testing, less influence from the residual stresses is expected, due to the machined samples.

- Hydrogen-related causes:

  Based on the finding of areas of intergranular cracking on the fracture surface from break load testing, hydrogen should be discussed as a possible contributing cause, as intergranular cracking is a typical observation in hydrogen-related crack growth. Hydrogen-related cracking is generally dependent on a combination of three different factors /9/: Presence of hydrogen, tensile stress and a susceptible material. Based on the high hardness of the material in all the examined chain samples, the material is considered susceptible to hydrogen embrittlement and/or hydrogen-assisted cracking, see also assessment of hardness of chain material in previous report /1/. Potential sources of hydrogen are limited to production, as no damage of the coating or corrosion has been seen visually, excluding potential external sources. The chain samples (both reference chain from 2021, BJC/2 and current sample MJA/4) are also stored in relatively dry conditions, hence not exposed to significant corrosion giving potential hydrogen formation. As the chain segment has not been in use, it has not been loaded after production (proof loading at manufacturer), apart from potential residual stress. During cutting of the chain links, compressive residual stresses were noted, as the saw blade got caught in the chain link, as soon as the link was cut through. Based on an assessment of all the three factors, it is not very likely that hydrogen is a contributing cause for the low actual break load. The areas of intergranular crack growth can also be a direct result of the high strength material.

- Variation in properties within the lot:

  Testing has shown actual break load and hardness that does not correspond to the certificate values. Differences in tensile test results between different links are also seen. The mechanical properties of the chain are generally related to the heat treatment of the chain. The material has been through a quench and temper heating process, however no more details are received. The fact that there are large variations in mechanical properties, and that test results do not meet requirements (high hardness, varying ductility properties and low break load) indicate that the tempering part of the quench and temper heating process has not been successful. This is also supported by the somewhat lower hardness close to the surface compared to the higher values in the core/main part of the cross section, i.e., better tempering on the outside. The visual appearance of the microstructure is as expected, a quenched and tempered microstructure, however large differences in mechanical properties can be found without a clear difference in the visual appearance of the microstructure. This indicates that there are high variations in the properties of the chain, which has not been identified by the quality control of the manufacturer. No detailed information regarding heat treatment has been received and hence no assessment of possible direct causes related to this has been performed.

Summarized, all the effects believed to be contributing to the observed low actual break load are considered to be related to production and not storage of the chain. The chain samples have not been in use; hence this is not considered relevant.

# 5 REFERENCES

/1/ DNV Report no. 2021-5360; Failure of chain link onboard Cornishman – Failure investigation, 2021.

/2/ NS-EN 818-2; Short link chain for lifting purposes - Safety - Part 2: Medium tolerance chain for chain slings - Grade 8, 2008.

/3/ ASTM A391; Standard Specification for Grade 80 Alloy Steel Chain, 2021.

/4/ NS-EN ISO 6892-1; Metallic materials — Tensile testing — Part 1: Method of test at room temperature, 2019.

/5/ DNV-OS-E302; Offshore mooring chain, 2022.

/6/ NS-EN ISO 6507-1; Metallic materials — Vickers hardness test — Part 1: Test method, 2018.

/7/ NS-EN ISO 18265; Metallic materials — Conversion of hardness values; 2013.

/8/ NS-EN 818-1; Short link chain for lifting purposes – Safety – Part 1: General conditions of acceptance, 2008.

/9/ ASM Handbook, Volume 11: Failure analysis and Prevention, 2002: Hydrogen damage and embrittlement.

Image courtesy of Det Norske Veritas

# APPENDIX A
## Chain certificate

Image courtesy of Det Norske Veritas

DNV

GRUPA KAPITAŁOWA **FASING S.A.**

FASING S.A.

INTEGRATED QUALITY AND ENVIRONMENT MANAGEMENT SYSTEM

SUPERVISED BY TÜV NORD Polska

PN-EN ISO 9001:2009: AC090 100/1267/64/2015
PN-EN ISO 14001:2005: AC090 104/1267/64/2015

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fax. +48 32 258 15 60
Dział Eksportu tel. +48 32 735 00 00 w. 465, 469, 584
fax +48 32 258 12 71
SERWIS tel. +48 32 735 00 00 w. 467, 468

| INSPECTION CERTIFICATE No.: | E-118/2019 | "Type 3.1" acc. to PN-EN 10204 |
|---|---|---|

| Chain / Type (Designation) | 32 x 96<br>( size | 8<br>grade | 2 strands x 50 m<br>other | 63200081<br>catalogue No.) |
|---|---|---|---|---|
| produced acc. to | EN 818-2<br>( standard | | -<br>technical requirements | ASTM A 391/A<br>other ) |

| | | | |
|---|---|---|---|
| Date of receipt: | 2019-04-23 | Ordering party: | George Taylor & Co., UK |
| Producer/ Supplier: | Mining Tools and Equipment Factories Capital Group FASING Plc. | User: | - |
| | | Purchase Orde No.: | 76570 |
| Quantity supplied: | 100 m | Contract No.: | - |
| Production Order No.: | DE1/112/2019 | Purchase Ordedate: | 2019-04-12 |

| Item | Tested parameter or measured quantity | | | Unit of measurement | Required value | Sample No. 1 (Measured value) |
|---|---|---|---|---|---|---|
| 1 | Nominal diameter of the round link | | $d_n$ | mm | 32±1,6 | 32,7 |
| 2 | Thickness of the flat link | | - | mm | - | - |
| 3 | Weld diameter | | $d_s$ | mm | max.37,0 | 33,2 |
| 4 | Weld width | | - | mm | - | - |
| 5 | Pitch | round link | p | mm | 96±2,9 | 96,1 |
| | | flat link | - | mm | - | - |
| 6 | Inside width | round link | $w_1$ | mm | min.41,6 | 46,4 |
| | | flat link | - | mm | - | - |
| 7 | Outside width | round link | $w_2$ | mm | max.118 | 111,2 |
| | | flat link | - | mm | - | - |
| 8 | Crown radius | | r | mm | - | - |
| 9 | Length of 11 links | | l | mm | 1056+5,3 | 1057,1 |
| 10 | Manufacture proof force | | MPF | kN | 804 | 804 |
| 11 | Breaking Force | | Fa/BF | kN | min.1290 | 1480 |
| 11a | ~~Working Force~~/Working Load Limit | | WF/WLL | kN/ t | max.31,5 | 31,5 |
| 12 | Break place: L- leg; C - crown; W - weld | | | | | C |
| 13 | Elongation under test force | | Ep | % | - | - |
| 14 | Elongation at fracture | | Ek | % | min.20 | 38,5 |
| 15 | Deflection | | f | mm | 26 | 26 |
| 16 | Charpy-V-test | | KV | J | - | - |
| 17 | Hardness | | UNIT<br>* HRC, HBW, HV | | - | - |
| 18 | Fatigue resistance | Lower load $F_u$ : - [kN] Upper load $F_o$ : - [kN] Frequency of load changes N : - [Hz] | T/N | cycles | - | - |
| 19 | Break place: L- leg; C - crown; W - weld | | | | | - |

| Chemical analysis of the material acc. to DIN 17115 / ~~PN-92/H-93028~~ | Heat No.: | C | Si | Mn | P | S | Cr | Mo | Ni | Al |
|---|---|---|---|---|---|---|---|---|---|---|
| | 221071 | 0,211 | 0,216 | 0,215 | 0,0154 | 0,0064 | 0,567 | 0,252 | 0,510 | 0,0281 |

(Chemical composition in percentages by weight)

Marking: H52-8 3/19

Remarks: Black painted ; 1194 kg

* delete as appropriate

[redacted]

stamp and signature

Department Manager

[redacted]

Management System Department

[redacted]

stamp and signature

Image courtesy of [Det Norske Veritas]

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HARBOUR ROAD
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CORNWALL
TR18 5HW GB

**ACCOUNT NO** 30014
**CERTIFICATE NO** 283213.0
**PAGE** 1

UK & EC DECLARATION OF CONFORMITY - All products are rated in metric tonnes.
These products are supplied in accordance with the Machinery Directive 2006/42/EC & Supply of Machinery (Safety) Regs 2008.

| DISTINGUISHING MARK | DESCRIPTION | QUANTITY | | ISSUE DATE | PROOF LOAD | WLL |
|---|---|---|---|---|---|---|
| HS2-8 3/19 | G8C32 **YOUR PO:** 15090 **GTO:** 107585<br>GRADE 8 SHORT LINK CHAIN 32MM DIA - G8C32 - TO BS EN 818 -2 - SAFETY FACTOR 4 TO 1 - MIN ELONGATION 20% | 8 | M | 23/09/2019 | 804 Kn | 31.5 Tonne |

**SIGNED ON BEHALF OF GEORGE TAYLOR & COMPANY BY:** ______ [redacted] _____ [redacted] **Date: 08/02/2021**

I hereby declare that the equipment described in this record was tested and/or examined by the manufacturer, was found free from any defect likely to affect safety and complies with the essential health & safety requirements of the Machinery Directive 2006/42/EC, the Supply of Machinery (Safety) Regulations 2008 and the Health & Safety at Work etc Act 1974 section 6. Safety information, operating instructions and privacy policy are available for download on our website at www.gtlifting.co.uk

The certificates and/or declarations of conformity issued by the manufacturer are held on file at our offices and can be made available to an appropriate enforcing authority if they make such a request.
The items detailed have been designed and produced to be suitable for normal duties when correctly used by a competent person. Where an item is to be used in abnormal conditions or for arduous duties reference should be made to the manufacturer before such use. Failure to do so may absolve the manufacturer from his responsibility under Section 6 of the Health & Safety at Work etc Act 1974.

Image courtesy of Det Norske Veritas

# APPENDIX B
## Test certificate, hardness

32 x 96 kl.8 - 2 odc.x 50 m - George Taylor & Co. - zlecenie DE1/112/2019 - wysyłka Kwiecień 2019 r.

| | | | NR | NR | | | min.20 | min.1290 | | | | | | | Gatunek | | | | Kalibrowanie | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MIESIĄC | Wielkość | DZIEŃ | PRÓBY | ŁAŃC. | CECHA | Ep% | Ek.[ % ] | Fz.[ kN ] | R/P/Z | HB | GIĘCIE | WYTOP | SERIA | Dostawca | MATERIAŁU | Udar. | Normal. | Pulsacja | il.zer | śr.siła | Norma | Klasa | metry | świad. | m-c |
| luty | 96 | 20.02.19 | 46 | 9 | H52-8 3/19 | - | 38,5 | 1480 | W | 373 | +26 | 221071 | 3/19 | Mittal Steel | 23GHNMA+V | - | - | - | 0 | 820 | EN 818-2 | 8 | 100 | E-118/2019 | 4 |

[redacted]

Image courtesy of Det Norske Veritas

# APPENDIX C
## Report from NDT

DNV

# MAGNETPULVER RAPPORT
# MAGNETIC PARTICLE REPORT

OCEANEERING®

| | | | |
|---|---|---|---|
| Kunde PO/Customer PO<br>**1822489** | Vårt prosjektnr./Our project no.<br>**0000223300/8003** | Rapportnr / Report no<br>**1160666** | Rev<br>**1** |
| Kunde/Client<br>**DNV GL AS** | Antall vedlegg/Appendixes<br>**2** | Testdato/Date of test<br>**2023-01-30** | |
| Adresse/Address<br>**Veritasveien 1** | Prosedyre/Procedure<br>**NS-EN ISO 17638: 2016** | Aksept standard/Accept std.<br>**No indications** | |
| Postaddresse / Postal address<br>**1363 Høvik** | Omfang/Extent<br>**100%** | Resultat/Result<br>**Akseptert/Accepted** | |
| Kontaktperson/Supervisor<br>[redacted] | Utstyr/Equipment<br>**Bycotest 101 / Yoke** | Materiale/Material<br>**CS** | |

| | |
|---|---|
| Undersøkelsested/Test site<br>**DNV Marineholmen** | Tegning nr./Drawing No.<br>--- |
| Inspeksjon av/Inspection of<br>**MJA/4 32 mm 8 chainlinks** | |

| | | | |
|---|---|---|---|
| Overflate/Surface<br>**Coated** | Sveisemetode/Welding proc.<br>--- | Fugetype/Joint<br>--- | Varmebehandlet/Heat treated<br>--- |
| Feltstyrke/Field strength<br>**2,3-4,5 kA/m** | Feltindikator/Field indicator<br>**Castrolstrips Type II** | Kontrastmaling/Contrast paint<br>--- | Magnetisert for/Magnatized for<br>**Longetdinal / Transverse** |

| | | |
|---|---|---|
| Spole/Coil: ☐<br>Type:<br>Strøm/Current: | Yoke: ☑<br>Type: **Magnaflux Y6**<br>S.Max: **150 mm**<br>Strøm/Current: **AC** | Annen/Other: ☐ |

| | |
|---|---|
| Kontrollmiddel/Examination medium<br>Våt/Wet: ☑ Tørr/Dry: ☐ | Kontrollmiddel/Examination medium<br>Svart/Black: ☐ Fluoriserende/Fluorescent: ☑ |

Anmerkninger/Comments

**Extent of inspection:**
**-----------------------**

**100% Fluorescent magnetic particle inspection of 8 no of chainlinks.**
**Coating below 50µ.**

Resultat/Results

**Accepted**

| | |
|---|---|
| Dato/Date Operatør/Operator<br>2023-02-02 [redacted] | Dato/Date Rapport godkjent/Report approved<br>2023-02-02 [redacted] |

Oceaneering Asset Integrity AS - Sandslimarka 61-63, N-5254 Sandsli - Tel: + 47 56 31 60 00, NO 965 591 095 MVA

www.oceaneering.com



1 av/of 4

Image courtesy of Det Norske Veritas

| | |
|---|---|
| MJA/4 32 mm 8 chainlinks | OCEANEERING |
| 18.01.2023 | Appendix 1 of 1 |

Image courtesy of Det Norske Veritas

DNV

NORDTEST

# EN ISO 9712

## NDT LEVEL 2 CERTIFICATE

**Test method: Magnetic Particle Testing**

NORSK AKKREDITERING PERS 002

[redacted]

**Number:** **8884-N2-M**

**Date of issue:** **2019-10-03**

**Valid from:** **2022-05-01**

**Date of expiry:** **2024-10-02**

**Date of birth:**
1976-04-07

[redacted]

Fulfils the requirements according to the directives 2014/68/EU respectively 2010/35/EU PED/TPED

The certificate holder fulfills all requirements of EN ISO 9712 and NORDTEST DOC GEN 010.

| | |
|---|---|
| **Industrial sector:** | **IPI: comprising sectors c, f, w, t, wp** |
| **Supplemental sector:** | **None** |
| **Limitations:** | **No limitations** |
| **Remarks:** | |

**Initial certification body:**
FORCE Technology Norway Certification

Per-Arvid Lid
2022-05-06
Digitally signed by Per-Arvid Lid
pal@force.no
Head of Department
FORCE Technology Norway Certification

The electronic version of the certificate, saved in FORCE Cert NDT Online, is the newest version and is defined original. The digital signature can be validated e.g. in Adobe Acrobat Reader, and the status of the certificate can be validated on FORCE Cert NDT Online.

FORCE Tech. Certification - Mjåvannsveien 79 - 4628 KRISTIANSAND S - Norway - Phone: +47 64 00 35 00 - E-mail: ndtsert@force.no

**Number: 8884-N2-M**

**Operating authorization by employer:**

**Oceaneering Asset Integrity AS**
Sandslimarka 185, 5868 Bergen, Norway

N-007

| | |
|---|---|
| 2022-05-06 | 2022-10-02 |
| [redacted] | [redacted] |
| Authorized signature/Employer; first time issue | Authorized signature/Employer; renewed 1st year |

The electronic version of the certificate, saved in FORCE Cert NDT Online, is the newest version and is defined original. The digital signature can be validated e.g. in Adobe Acrobat Reader, and the status of the certificate can be validated on FORCE Cert NDT Online.

FORCE Tech. Certification - Mjåvannsveien 79 - 4628 KRISTIANSAND S - Norway - Phone: +47 64 00 35 00 - E-mail: ndtsert@force.no

Image courtesy of Det Norske Veritas

# APPENDIX D
## Report from chemical analysis

Image courtesy of Det Norske Veritas

DNV

D-LAB
DEGERFORS LABORATORIUM AB

1 (1)

# Provningsresultat / Test Results:

Ordernr / Orderno
DL-75584

| Beställare / Client | Referens / Reference |
|---|---|
| DNV GL AS | [redacted] |

Adress / Address
P.O. Box 300,Org. ID No: 945748931MVA, NO-1322 HÖVIK

| Er beställning / Your order No | Ankomstdag / Sample Registration Date | Utskriftsdatum / Date of issue | DL ID |
|---|---|---|---|
| 1822035 | 2023-01-30 | 2023-01-30 | 726874 |

Provbeteckning / Sample identity
Steel sample

Noteringar / Notes

| Resultat/ Results | | Mätosäkerhet/ Uncertainty of measurement | Ackrediterat mätområde Accredited range of measurement | Standard metod Standard method | Dlab metod/ Dlab method |
|---|---|---|---|---|---|
| C | 0.221 % | 0.009 % | 0.0020 - 5.0 % | ASTM E 1019-18 | 5.4-058M |
| Si | 0.21 % | 0.007 % | 0.01 - 4 % | ASTM E 572-21 | 5.4-051M |
| Mn | 1.26 % | 0.010 % | 0.01 - 15 % | ASTM E 572-21 | 5.4-051M |
| P | 0.017 % | 0.003 % | 0.002 - 0.05 % | ASTM E 1086-22 | 5.4-057M |
| S | 0.004 % | 0.001 % | 0.0010 - 0.35 % | ASTM E 1019-18 | 5.4-058M |
| Cr | 0.56 % | 0.008 % | 0.01 - 30 % | ASTM E 572-21 | 5.4-051M |
| Ni | 0.51 % | 0.01 % | 0.01 - 40 % | ASTM E 572-21 | 5.4-051M |
| Mo | 0.27 % | 0.002 % | 0.01 - 8 % | ASTM E 572-21 | 5.4-051M |
| Ti | 0.003 % | 0.003 % | 0.003 - 2 % | ASTM E 572-21 | 5.4-051M |
| Nb | < 0.005 % | ** | 0.005 - 2 % | ASTM E 572-21 | 5.4-051M |
| Cu | 0.14 % | 0.003 % | 0.01 - 4 % | ASTM E 572-21 | 5.4-051M |
| Co | 0.007 % | 0.001 % | 0.005 - 16 % | ASTM E 572-21 | 5.4-051M |
| N | 0.006 % | 0.001 % | 0.0002 - 0.50 % | ASTM E 1019-18 | 5.4-061M |
| Sn | < 0.02 % | ** | 0.02 - 0.1 % | ASTM E 572-21 | 5.4-051M |
| W | 0.02 % | 0.002 % | 0.01 - 17 % | ASTM E 572-21 | 5.4-051M |
| V | 0.064 % | 0.001 % | 0.005 - 4 % | ASTM E 572-21 | 5.4-051M |
| Al | 0.028 % | 0.005 % | 0.01 - 0.3 % | ASTM E 1086-22 | 5.4-057M |
| Ta | < 0.002 % | * | - | ASTM E 1086-22 | 5.4-057M |
| Ca | 0.0010 % | * | - | ASTM E 1086-22 | 5.4-057M |
| B | 0.0003 % | 0.00006 % | 0.0002 - 0.005 % | ASTM E 1086-22 | 5.4-057M |
| As | 0.005 % | 0.0006 % | 0.001 - 0.030 % | ASTM E 1086-22 | 5.4-057M |
| Fe | 96.66 % | * | | | |

* Ej ackrediterad analys / Not accredited analysis
** Ej ackrediterad analys, resultat utanför ackrediterat område / Not accredited analysis, result outside accreditation range

The reported uncertainty is based on a standard uncertainty multiplied by a coverage factor of k=2, providing a level of confidence of approximately 95%
This report may not be reproduced other than in full, except with the prior written approval of the issuing laboratory.

Note: The results are only valid for the sample that has been delivered to the laboratory.
We are not responsible for electronically transferred reports due to changes of data during transmission. Please contact us in doubtful cases.

**DEGERFORS LABORATORIUM**

[redacted]

Laborant

Rapporten är signerad digitalt/
The report is digitally signed

Degerfors Laboratorium AB
Box 54
SE-693 21 DEGERFORS

Phone +46 586- 21 63 50

Web: www.degerforslab.se
Email: info@degerforslab.se

Bankgiro: 5735-6784
Bank: Swedbank, Degerfors
IBAN: SE8480000815629833744494

Image courtesy of Det Norske Veritas

# APPENDIX E
## Documentation of manganese content

Image courtesy of Det Norske Veritas

ORYGINAŁ

Program: FE-10
Komentarz: Stale niskostopowe bez O2
Średnia (n=2)

2019-02-01 08:26:54
Pierwiastki: Koncentracje Typu -> 162

GATUNEK: 23GHNMA+V (SŁ-pręty)
NR LAB.: 461-pręty fi.33.0

ZLECENIODAWCA: LM 1;Arcelor Warszawa
WYTOP/ILOŚĆ: 221071

| | C % | Si % | Mn % | P % | S % | Cr % | Ni % | Mo % | Al % | Co % |
|---|---|---|---|---|---|---|---|---|---|---|
| ⊥ | 0.190 | 0.120 | 1.140 | | | 0.400 | 0.470 | 0.220 | 0.0200 | |
| x | 0.211 | 0.216 | 1.215 | 0.0154 | 0.0064 | 0.567 | 0.510 | 0.252 | 0.0281 | 0.0076 |
| ⊤ | 0.260 | 0.280 | 1.460 | 0.0200 | 0.0200 | 0.650 | 0.730 | 0.380 | 0.0500 | |

ORYGINAŁ

| | Cu % | Nb % | Ti % | V % | W % | Sn % | As % | B % | N % | Fe % |
|---|---|---|---|---|---|---|---|---|---|---|
| ⊥ | | | | 0.054 | | | | | | |
| x | 0.143 | 0.0029 | 0.0016 | 0.058 | 0.004 | 0.0043 | 0.0032 | <0.0001 | 0.0028 | 96.75 |
| ⊤ | 0.230 | | | 0.066 | | 0.0100 | 0.0100 | 0.0008 | 0.0120 | |

ORYGINAŁ

Program: FE-10
Komentarz: Stale niskostopowe bez O2
Średnia (n=2)

2019-02-01 08:29:03
Pierwiastki: Koncentracje Typu -> 162

GATUNEK: 23GHNMA+V (SŁ-pręty)
NR LAB.: 462-pręty fi.33.0

ZLECENIODAWCA: LM 2;Arcelor Warszawa
WYTOP/ILOŚĆ: 221071

| | C % | Si % | Mn % | P % | S % | Cr % | Ni % | Mo % | Al % | Co % |
|---|---|---|---|---|---|---|---|---|---|---|
| ⊥ | 0.190 | 0.120 | 1.140 | | | 0.400 | 0.470 | 0.220 | 0.0200 | |
| x | 0.202 | 0.221 | 1.225 | 0.0150 | 0.0067 | 0.568 | 0.506 | 0.249 | 0.0320 | 0.0072 |
| ⊤ | 0.260 | 0.280 | 1.460 | 0.0200 | 0.0200 | 0.650 | 0.730 | 0.380 | 0.0500 | |

ORYGINAŁ

| | Cu % | Nb % | Ti % | V % | W % | Sn % | As % | B % | N % | Fe % |
|---|---|---|---|---|---|---|---|---|---|---|
| ⊥ | | | | 0.054 | | | | | | |
| x | 0.141 | 0.0030 | 0.0017 | 0.058 | 0.004 | 0.0042 | 0.0032 | <0.0001 | <0.0008 | 96.76 |
| ⊤ | 0.230 | | | 0.066 | | 0.0100 | 0.0100 | 0.0008 | 0.0120 | |

ORYGINAŁ

Program: FE-10
Komentarz: Stale niskostopowe bez O2
Średnia (n=2)

2019-02-01 08:30:15
Pierwiastki: Koncentracje Typu -> 162

GATUNEK: 23GHNMA+V (SŁ-pręty)
NR LAB.: 463-pręty fi.33.0

ZLECENIODAWCA: LM 3;Arcelor Warszawa
WYTOP/ILOŚĆ: 221071

| | C % | Si % | Mn % | P % | S % | Cr % | Ni % | Mo % | Al % | Co % |
|---|---|---|---|---|---|---|---|---|---|---|
| ⊥ | 0.190 | 0.120 | 1.140 | | | 0.400 | 0.470 | 0.220 | 0.0200 | |
| x | 0.214 | 0.219 | 1.223 | 0.0158 | 0.0069 | 0.563 | 0.513 | 0.252 | 0.0307 | 0.0071 |
| ⊤ | 0.260 | 0.280 | 1.460 | 0.0200 | 0.0200 | 0.650 | 0.730 | 0.380 | 0.0500 | |

ORYGINAŁ

| | Cu % | Nb % | Ti % | V % | W % | Sn % | As % | B % | N % | Fe % |
|---|---|---|---|---|---|---|---|---|---|---|
| ⊥ | | | | 0.054 | | | | | | |
| x | 0.142 | 0.0030 | 0.0017 | 0.058 | 0.004 | 0.0043 | 0.0033 | <0.0001 | 0.0009 | 96.74 |
| ⊤ | 0.230 | | | 0.066 | | 0.0100 | 0.0100 | 0.0008 | 0.0120 | |

**ArcelorMittal Warszawa Sp. z o.o**
ul. Kasprowicza 132, 01-949 WARSZAWA
fax: 48/22 8354222, 48/22 8340952, tlx:82-63-51

ŚWIADECTWO ODBIORU
INSPECTION CERTIFICATE
ABNAHMEPRÜFZEUGNIS
ACCORDING TO PN-EN 10204:2006
3.1.

Nr świadectwa 10870/2019(125) Data 2019-01-17
Numer potwierdzenia 945163/2018 **1/*10
Wydział: P20

Nabywca
Zamówienie Nr
DHKS/00243/2018/ZS
z dnia
2018-11-29

Nabywca (272550391)
KARBON 2 SPÓŁKA Z O.O.
MODELARSKA 11
40-142 KATOWICE
POLSKA

Niniejszym deklarujemy, że wyrób jest zgodny z normami i innymi dokumentami powołanymi w treści niniejszego dokumentu.

Wyrób (NPO) | Stan dostawy (+U) | Przeznaczenie wyrobu (PWp )
Pręty Gorącowalcowane Okrągłe | Surowy +U | do obróbki plastycznej

Gatunek 23GHNMA+V norma PN-92/H-93028 | Nr wytopu 221071

Wymiary [mm] Fi 33 +0,3/-0,3 Długość dokładna: 8,000 [m]
Tolerancja długości[+/-]: 200,0 [mm] 0,0 [mm]

Waga[kg] 21.560 Wiązki 8 Normy *

Skład chemiczny wytopu [%]

| C | Mn | Si | P | S | Cr | Ni | Cu | Mo | Al | Sn |
|---|---|---|---|---|---|---|---|---|---|---|
| 0,23 | 1,25 | 0,22 | 0,015 | 0,005 | 0,56 | 0,510 | 0,14 | 0,250 | 0,028 | 0,009 |
| B | V | As | Sb | O | H | N | 23 | | | |
| 0,00030 | 0,060 | 0,005 | 0,0020 | 0,0009 | 0,00013 | 0,0090 | 0,020 | | | |

23=S+P;

-Własności mechaniczne/Udarność zgodnie z PN-91/H-04310 / PN-EN 10045-1

| Kierunek | Re [MPa] | Rm [MPa] | A5 [%] | Z[%] | KV [J] |
|---|---|---|---|---|---|
| L | 1048 | 1186 | 12,0 | 58,0 | 42,0- 41,0- 41,0 |

Temperatura pomiaru udarności 20,0°C
Obróbka_cieplna_próbek_(+QT)
Hartow.1 Odpusz.1
890 °C w 470 °C p

-Udarność w temperaturze -20,0 °C zgodnie z ISO 148-1
Kierunek
L KV [J] = 10,0 - 13,0 - 10,0
Obróbka_cieplna_próbek_(+QT)
Hartow.1 Odpusz.1
890 °C w 470 °C p

-Hartowność Jominy HRC w mm zgodnie z PN-79/H-04402

| Odległości: | 1,5 | 3,0 | 5,0 | 7,0 | 9,0 | 11,0 | 13,0 | 15,0 | 20,0 | 25,0 | 30,0 | 35,0 | 40,0 | 45,0 | 50,0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wartości..: | 49,0 | 48,5 | 47,5 | 47,5 | 46,0 | 43,5 | 40,0 | 37,5 | 34,0 | 32,0 | 30,0 | 28,5 | 28,5 | 28,5 | 28,0 |

-Twardość powierzchnia zgodnie z EN ISO 6506-1
HB = 270,0 - 272,0

-Wielkość ziarna austenitu 7 - 8 zgodnie z PN-84/H-04507

-Wtrącenie niemetaliczne K -0- zgodnie z DIN 50602
K3 = 2,0

-Pasmowość struktury 3/2/A [Wzorzec, skala, szereg] zgodnie z PN-63/H-04504

-Próba głębokiego trawienia (Wzorce) zgodnie z PN-57/H-04501
I/ 2 II/ 2 III/ 1 IV/ 1 V/ 2 VI/ 1 VII/ 1 VIII/ 1

-Odwęglenie 0,20[mm] zgodnie z PN-75/H-04506

Corresponds to grade 23MnNiCrMo52 DIN 17115

Badanie wad powierzchniowych 100%
Spectrotest 100% - OK
Wady powierzchniowe max 0,3mm
Stopień przerobu 29.95

Odpowiedzialny: [redacted]
2019-01-30 19:44:32
kierownik mgr inż. B. [redacted]
ArcelorMittal
1/1

Image courtesy of Det Norske Veritas

# APPENDIX F
## Certificate of calibration, 3,200 kN tensile test machine

Image courtesy of Det Norske Veritas

# KALIBRERINGSBEVIS
*Certificate of calibration*

*Certificate No.:* CALDNV-0659-A/2022



Cal. Date: 26.04.2022

**Ormen Lange MessTek. Load cell HBM 3,2 MN "B".**
**S.no.: 011201 . Sense:=-335 Offset= -13**

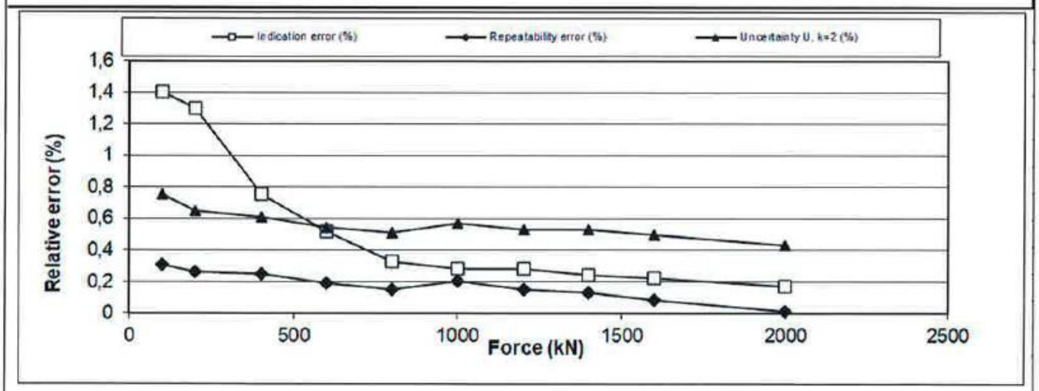
**Calibrated range: 2000 kN Tension** Temp. 17,5 C Software: Y211104a

**Reference: 2xSensotec1000kN tension**

| Force rel. 0 on calibrated equipment kN | Force rel. 0 on calibration normal kN | Relative Indication Error | Relative Repeatability Error | Relative Uncertainty U, k=2 |
|---|---|---|---|---|
| | | % of applied force | | |
| 100 | 98,67 | 1,4 | 0,31 | 0,75 |
| 200 | 197,50 | 1,3 | 0,26 | 0,65 |
| 400 | 397,03 | 0,75 | 0,25 | 0,61 |
| 600 | 596,9 | 0,52 | 0,19 | 0,54 |
| 800 | 797,4 | 0,33 | 0,15 | 0,51 |
| 1000 | 997,2 | 0,28 | 0,20 | 0,57 |
| 1200 | 1196,6 | 0,28 | 0,15 | 0,53 |
| 1400 | 1396,7 | 0,24 | 0,13 | 0,53 |
| 1600 | 1596,5 | 0,22 | 0,082 | 0,50 |
| 2000 | 1996,6 | 0,17 | 0,010 | 0,43 |

**Mean of zero errors after load cycles (kN):** **0,00**
**Largest relative resolution (%):** **0,10**

**Largest relative zero error after load cycles. (% of force range):** **0,00**
**Class assignments for the range: EN ISO 7500-1-Class = 2. DNVGL CALDNV-Class = 2.**




*This certificate of calibration may not be reproduced other than in full.*

Bevisets utstedelsesdato/*Date of issue:* 27. apr. 2022

Image courtesy of Det Norske Veritas

# KALIBRERINGSBEVIS
## *Certificate of calibration*

*Certificate No.:* CALDNV-0659-A/2022



Appendix.

Cal. Date: 26.04.2022

**Ormen Lange MessTek. Load cell HBM 3,2 MN "A".**
**S.no.: 011201 . Sense:=-335 Offset= -6,6**

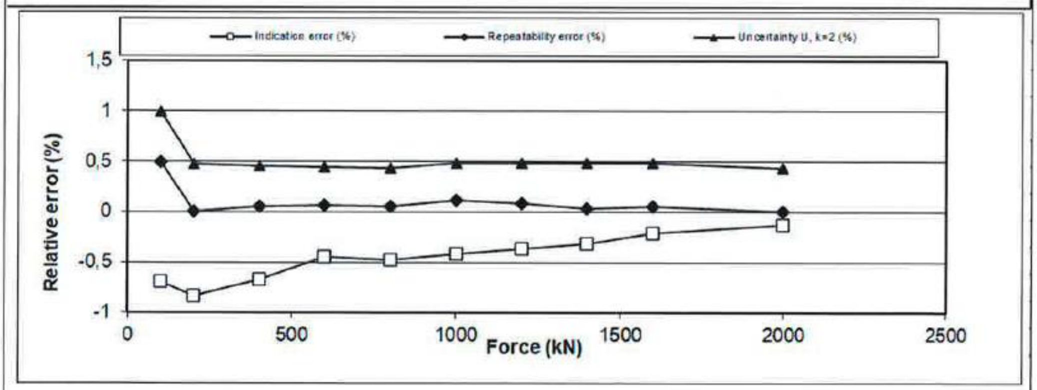
**Calibrated range: 2000 kN Tension** Temp. 17,5 C Software: Y211104a

**Reference: 2xSensotec1000kN tension**

| Force rel. 0 on calibrated equipment kN | Force rel. 0 on calibration normal kN | Relative Indication Error | Relative Repeatability Error | Relative Uncertainty U, k=2 |
|---|---|---|---|---|
| | | ------------ | % of applied force | ------------ |
| 100 | 100,70 | -0,69 | 0,49 | 1,0 |
| 200 | 201,70 | -0,84 | 0,00 | 0,47 |
| 400 | 402,7 | -0,67 | 0,049 | 0,45 |
| 600 | 602,7 | -0,45 | 0,066 | 0,44 |
| 800 | 803,8 | -0,48 | 0,050 | 0,43 |
| 1000 | 1004,2 | -0,42 | 0,12 | 0,48 |
| 1200 | 1204,5 | -0,37 | 0,083 | 0,48 |
| 1400 | 1404,5 | -0,32 | 0,035 | 0,48 |
| 1600 | 1603,4 | -0,21 | 0,056 | 0,48 |
| 2000 | 2002,5 | -0,13 | 0,0050 | 0,43 |

**Largest relative resolution (%):** **0,10**

**Class assignments for the range: EN ISO 7500-1-Class = 2. DNVGL CALDNV-Class = 1.**




*This certificate of calibration may not be reproduced other than in full.*

Bevisets utstedelsesdato/*Date of issue:* 27. apr. 2022

# KALIBRERINGSBEVIS
*Certificate of calibration*

*Certificate No.:* CALDNV-0659-A/2022



- Variations of the repeated measurements at the same force level.

The expanded relative measurement uncertainty, U, is shown for each load step in the column "Relative uncertainty U, k=2". It is reasonable to assume that for each load step, the force indicated on the machine, subtracted the shown relative indication error, with 95% probability, will not deviate more from the true force than the stated relative uncertainty. This provided that the machine has not changed since the calibration and is operated the same way and under the same conditions as during the calibration.

**Calibration environment**
The temperature is given in the result table for each calibrated range.

**Range classification and detailed results**

| Machine range data | | Machine range class assignment | | |
|---|---|---|---|---|
| Range | Scale division | Range | Largest relative resolution (%) | ISO/DNV class |
| 2000kN Tension A | 0,1 kN | 100 - 2000 kN | 0,1 | 2 / 1 |
| 2000kN Tension B | 0,1 kN | 100 - 2000 kN | 0,1 | 2 / 2 |
| 2000kN Tension B | 0,1 kN | 400 - 2000 kN | 0,025 | 2 / 1 |

**Calibration results**
The result tables and error diagrams are shown for each calibrated range on the next pages. The error calculation methods and the maximum permissible errors for each machine class are shown in the

 Bevisets utstedelsesdato/*Date of issue:* 27. apr. 2022

DNV

DNV

# KALIBRERINGSBEVIS
*Certificate of calibration*

*Certificate No.:* CALDNV-0659-A/2022



**Traceability**
The force reference normal was calibrated at RI.SE, Borås, with traceability to mass and gravitational acceleration. Bridge amplifiers were calibrated at HBM GmbH, Darmstadt, under DKD-accreditation.

**Calibration method**
The calibration was carried out according to DNV GLs Operating procedure: OP-O-NP-5-CAL011-04 KALIBRERING AV PRØVEMASKINER FOR STREKK- ELLER TRYKKBELASTNING (Calibration of testing machines for tension- and/or compression force) which embraces EN ISO 7500-1. The force reference normal was loaded by the calibrated machine in series with its force measuring device.

**Adjustments**
The machine was adjusted by a linearization table based on an initial load cycle taken in 2109. Deviation from said procedure: The table values are not analysed and reported. This might reduce the indication error but not the uncertainty.

| | Correction table | Correction table |
|---|---|---|
| kN | kN "A" | kN "B" |
| 0 | 0 | 0 |
| 200 | 200 | 196 |
| 400 | 399 | 394 |
| 600 | 598 | 593 |
| 800 | 796 | 791 |
| 1000 | 995 | 990 |
| 1200 | 1194 | 1189 |
| 1400 | 1393 | 1388 |
| 1600 | 1592 | 1588 |
| 1800 | 1791 | 1787 |
| 2000 | 1989 | 1986 |
| 2600 | 2586 | 2584 |
| 3200 | - | 3182 |

**Special calibration conditions**
- Increasing load only

**Calibration uncertainty**
The measurement uncertainty has been calculated for each load step according to the document EA-4/02 and includes:
- Uncertainty of the force reference, including long and short term effects.
- Uncertainty due to temperature variations.
- Uncertainty of the force reference indicator.
- Uncertainty of the calibration method.
- Measurement resolution of the calibrated machine.



Bevisets utstedelsesdato/*Date of issue:*
27. apr. 2022

DNV

DNV

# KALIBRERINGSBEVIS

Version 3.39 (2021-10-29)

## *Certificate of calibration*

Nr./*No.*: CALDNV-0659-A/2022

DNV AS
Section: Materials Lab - Oslo (E-NQ-TM).

Delivery address: Veritasveien 1, 1363 Høvik, Norway
Postal address: P. O. Box 300, 1323 Høvik, Norway.
Phone : +47 67579900

Side/*Page: 1 of 6*
Måleprotokoll/*Ref. to records:*
10049994-2

| Dag og sted for kalibrering/*Date and place of calibrations:* 26 April 2022 on the Client's premises | Bevisets utstedelsesdato/*Date of issue:* 27. apr. 2022 |
|---|---|
| Kalibrering utført av/*Calibration done by:* [redacted] | Ansvarlig/ *Responsible: Funksjon / Function* [redacted] Digitally signed by [redacted] Date: 2022.04.28 10:51:52 +02'00' |

**CALIBRATION OF TENSILE TESTING MACHINE**

**Client**
DNV- Bergen
Damsgårdsveien 111
5058 BERGEN

**Equipment Calibrated and its Identification**

Ormen Lange

| | |
|---|---|
| Manufacturer | : MessTek |
| Model | : Load cell HBM 3,2 MN |
| Serial No. | : 106405 / Load cell: 011201 |
| Rated capacity | : 3200 kN |
| Year of manufacture | : |
| Force indicator system | : MessTek, Dyn. Reg Version 7.4<br>Sensor files: Load cell HBM 3_2MN_*_011201_2019.trd |

**Reference instruments used**

| Description | Capacity | Make | Type | Serial nr |
|---|---|---|---|---|
| Load cell | 1000kN | Sensotec | RM/2698 | 76466 |
| Load cell | 1000kN | Sensotec | RM/2698 | 76467 |
| Bridge amplifier | ±2-5 mV/V | HBM GmbH | MX238B | 0009E5017800 |

*This certificate of calibration may not be reproduced other than in full.*

DNV

# KALIBRERINGSBEVIS
## *Certificate of calibration*

*Certificate No.:* CALDNV-0659-A/2022



**APPENDIX**

CALCULATION OF ERRORS

The errors shown in the table(s) are calculated from 3 force applications with increasing loads:

Indication error (q): Relative repeatability error (b):

$$q_I = \frac{F_{iI} - F_I}{F_I} x\,100 \qquad q = \frac{(q_1 + q_2 + q_2)}{3} \qquad b = q_{\max} - q_{\min}$$

where

| | | | |
|---|---|---|---|
| | $q_I$ | = | The I-th measurement of the relative indication error of the force-measuring |
| I | I | = | indicate load series number |
| | $F_i$ | = | force reading on the indicator on the testing machine |
| | $\overline{F}$ | = | arithmetic mean value of the force read on the force reference. |
| | $F_{\max}$ | = | highest force read on the force reference. |
| | $F_{\min}$ | = | lowest force read on the force reference. |

NOTE:

A negative q means that the indicator on the machine shows too low value
A positive q means that the indicator on the machine shows too high value

TESTING MACHINE CLASS ACCORDING TO EN ISO 7500-1

An additional requirement to the below table is that the assigned machine class can not be better than the class assigned to the reference load cell during its last calibration.

| Class of Machine | Maximum permissible error, % | | | | |
|---|---|---|---|---|---|
| | Indication q | Repeatability b | Reversibility[1)] V | Zero $f_0$ | Relative resolution a |
| 0,5 | ±0,5 | 0,5 | ±0,75 | ±0,05 | 0,25 |
| 1 | ±1,0 | 1,0 | ±1,5 | ±0,1 | 0,5 |
| 2 | ±2,0 | 2,0 | ±3,0 | ±0,2 | 1,0 |
| 3 | ±3,0 | 3,0 | ±4,5 | ±0,3 | 1,5 |

3) The verification of reversibility shall only be carried out on request (see 6.4.8 EN ISO 7500-1)

TESTING MACHINE CLASS ACCORDING TO DNV GL CALDNV

In this alternative to the EN ISO 7500-1 class assignment, the indication error, q, is increased by the relative expanded uncertainty in the applied force, $U_f$ k=2, while the class assigned to the reference load cell is not considered. This alternative indication error is calculated as $q' = \sqrt{(q^2+U_f^2)}$. The class is then determined according to the above table using q' instead of q. As the $U_f$ also includes uncertainties for the reference load cell during the last and previous calibrations, temperature effects and the indicating instrument, DNV GL regards this as a more adequate way of determining the indication error.

\- o0o –

 Bevisets utstedelsesdato/*Date of issue:* 27. apr. 2022

Image courtesy of Det Norske Veritas

Image courtesy of Det Norske Veritas

## About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

Whether assessing a new ship design, optimizing the performance of a wind farm, analyzing sensor data from a gas pipeline or certifying a food company's supply chain, DNV enables its customers and their stakeholders to make critical decisions with confidence.

Driven by its purpose, to safeguard life, property, and the environment, DNV helps tackle the challenges and global transformations facing its customers and the world today and is a trusted voice for many of the world's most successful and forward-thinking companies.

MAIB Safety Bulletin SB1/2024 – *Honeybourne III*

MAIB
MARINE ACCIDENT INVESTIGATION BRANCH

# SAFETY BULLETIN

SB1/2024

FEBRUARY 2024



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All bulletins can be found on our website:
https://www.gov.uk/maib

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## Fatal injury to a deckhand following a chain failure

## on the scallop dredger

## *Honeybourne III* (PD905)

## approximately 16 nautical miles south of Newhaven, England

## on 6 October 2023

*Honeybourne III*

## MAIB SAFETY BULLETIN 1/2024

This document, containing safety lessons, has been produced for marine safety purposes only, on the basis of information available to date.

*The Merchant Shipping (Accident Reporting and Investigation) Regulations 2012* provide for the Chief Inspector of Marine Accidents to make recommendations at any time during the course of an investigation if, in his opinion, it is necessary or desirable to do so.

The Marine Accident Investigation Branch is carrying out an investigation into the fatal injury to a deckhand following the failure of a chain on the scallop dredger *Honeybourne III* (PD905).

The MAIB will publish a full report on completion of the investigation.

**Captain Andrew Moll OBE**
**Chief Inspector of Marine Accidents**

**NOTE**

This bulletin is not written with litigation in mind and, pursuant to Regulation 14(14) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012, shall not be admissible in any judicial proceedings whose purpose, or one of whose purposes, is to apportion liability or blame.

**This bulletin is also available on our website: www.gov.uk/maib**
**Press Enquiries: 01932 440015 Out of hours: 020 7944 4292**
**Public Enquiries: 0300 330 3000**

## BACKGROUND

At about 2345 on 6 October 2023, the lifting arrangement for the dredging gear that was suspended from the raised port derrick on the UK registered scallop dredger *Honeybourne III* (PD905) fell to the deck without warning. The gear struck a deckhand working below, causing serious head injuries.

The crew of *Honeybourne III* alerted His Majesty's (HM) Coastguard and administered first aid to the unconscious deckhand. HM Coastguard tasked a search and rescue helicopter and a Royal National Lifeboat Institution (RNLI) lifeboat to assist, but the deckhand was declared deceased by the attending helicopter paramedic.

## INITIAL FINDINGS

The ongoing MAIB investigation has found that a section of chain in the port dredging gear quick-release assembly failed as the gear was being retrieved. A 32mm chain link, which was led over a static steel pin at the derrick head **(Figure 1)**, parted **(Figure 2)** and allowed the towing block, monkey face block and associated gear to fall to the deck below.

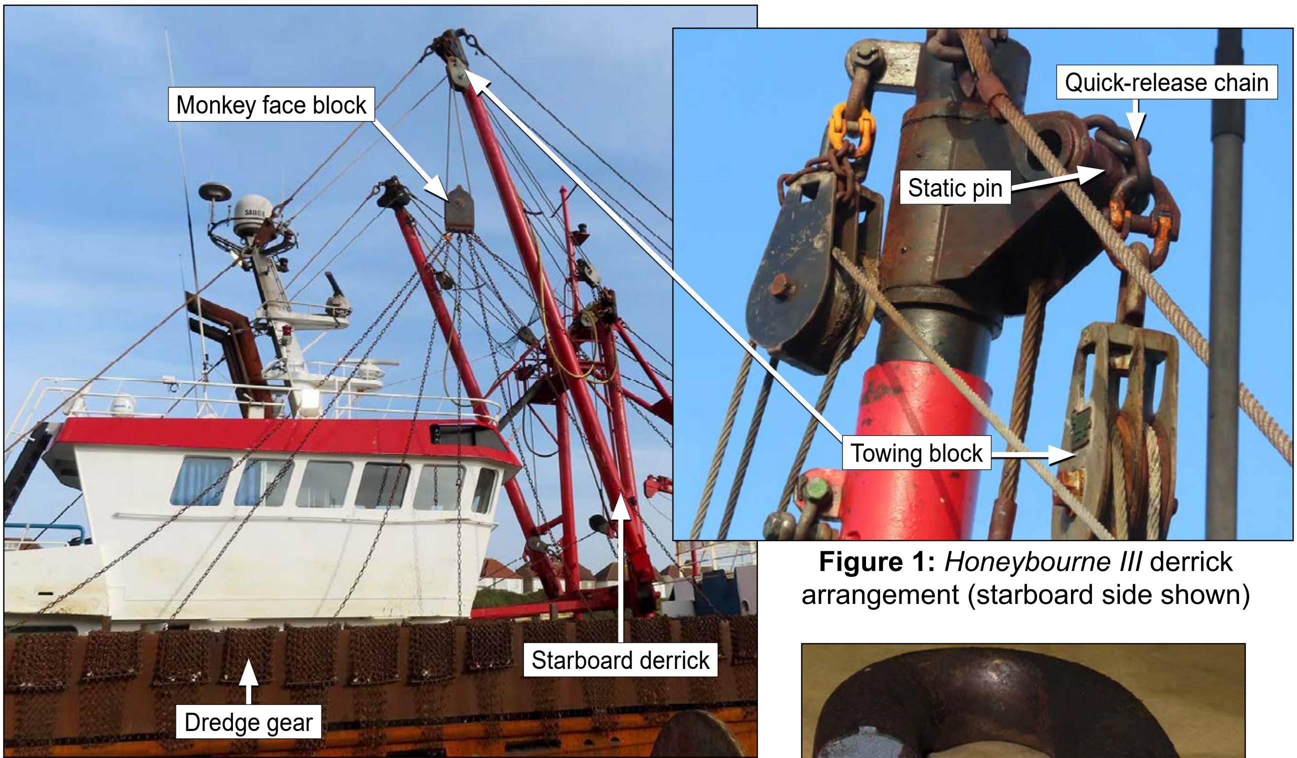


**Figure 1:** *Honeybourne III* derrick arrangement (starboard side shown)

The configuration of a chain led over a static pin as part of a quick-release gear is commonly used on board scallop dredgers and beam trawlers. Such arrangements are known to have failed previously and chain fractures have been identified during routine inspections of quick-release gear **(Figure 3)**.

**Figure 2:** Failed chain link on *Honeybourne III*

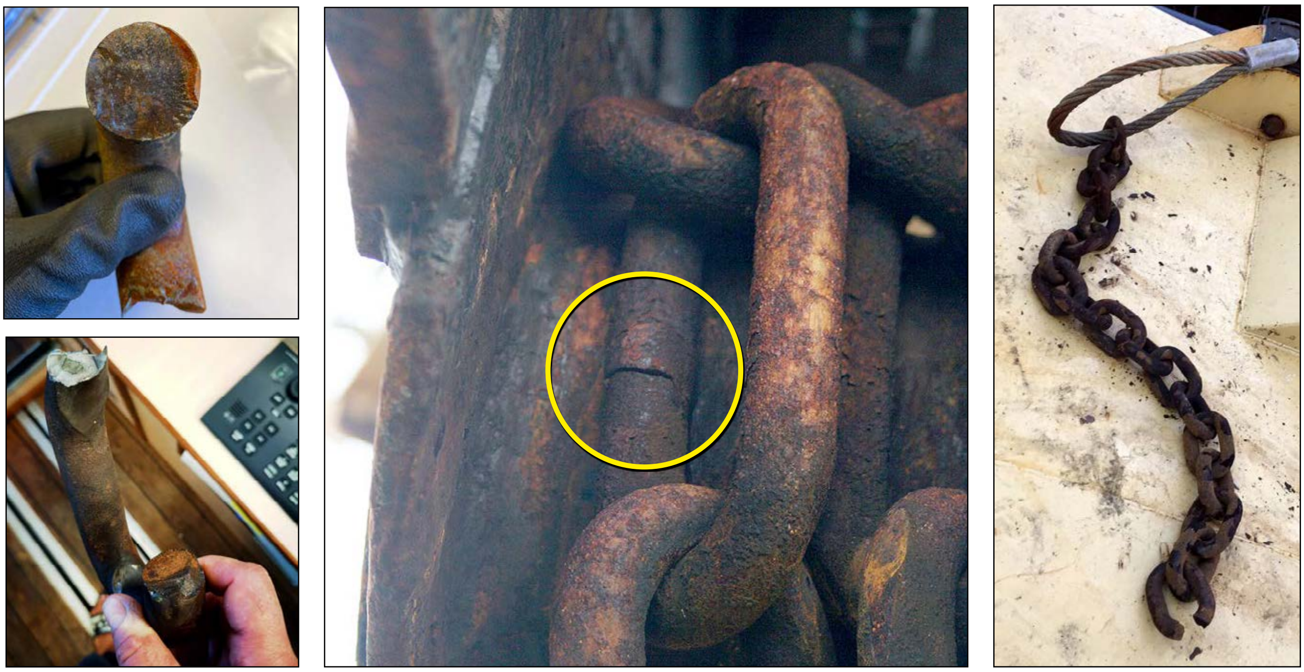

**Figure 3:** Identified chain defects in static pin arrangements

In February 2021, the failure of a similar chain to that which failed on board *Honeybourne III* resulted in the death of a deckhand on board the beam trawler *Cornishman* (PZ512). As a result, the Maritime and Coastguard Agency (MCA) issued Safety Bulletin 20[1] in August 2021. The safety bulletin highlighted the need for action by owners, operators, skippers, crew and safety advisors to ensure that for vessels under their control they:

- *Have an inspection regime sufficient to inspect all items of lifting equipment including those likely to be subject to high load, high wear and high impact;*
- *Have provided the competent person sufficient opportunity under appropriate conditions to be able to make an assessment for continued operation – which may require inspection techniques other than visual;*
- *Have determined the parameters within manufacturer's recommendations for continued acceptance of items of lifting equipment;*
- *Have determined the frequency of inspection, and where the risk indicates possibility of premature failure, to increase the frequency of inspection in accordance with the Regulations*[2]*;*
- *Have a system to record all inspections and changes to lifting equipment.*

Safety Bulletin 20 built on concerns raised in MCA Safety Bulletin 17, issued in October 2020[3], regarding the safety of lifting operations on fishing vessels. That safety bulletin noted that:

> *It is the owner's responsibility to identify key areas of risk in respect of lifting operations in accordance with the Fishing Vessels (Health and Safety at Work Regulations 1997 (SI 1997/2962)…*

---

[1] MCA Safety Bulletin 20: Safety concern over lifting equipment inspections on fishing vessels (https://www.gov.uk/government/publications/safety-bulletin-20-safety-concern-over-lifting-equipment-inspections-on-fishing-vessels).

[2] Merchant Shipping and Fishing Vessels (Lifting Equipment and Lifting Operations Regulations) 2006 (SI 2006/2184).

[3] Safety Bulletin 17: Safety concern over lifting operations on fishing vessels (https://www.gov.uk/government/publications/safety-bulletin-17-safety-concern-over-lifting-operations-on-fishing-vessels).

*…If a lifting operation cannot be undertaken safely then it shall not continue.*

In May 2022, the MAIB issued an interim report on the investigation into the fatal accident on board *Cornishman*. The interim report highlighted that an arrangement containing a chain passing over a static pin makes it *very difficult to calculate the tensile strength of the arrangement and makes it more susceptible to failure*. The interim report further stated that:

> *It is therefore imperative in the short-term that these types of release mechanisms and derrick head pins are subject to regular inspection and replaced at the earliest sign of wear.*

Alternative arrangements for the quick-release mechanisms at the derrick head that either do not include a chain passing over a static pin, or remove the risk of the gear falling in the event of a failure, have been fitted to vessels to mitigate the risk of gear falling from height in the event of a failure of the chain arrangement. The alternative configurations observed by the MAIB have included the use of wire and sheave arrangements **(Figure 4)**, the replacement of the derrick head arrangement with a swinging arm mechanism **(Figure 5)**, and the provision of warp tension monitoring and release systems. Options have also been suggested for a secondary means of retaining the gear, in addition to the chain, to prevent the gear from falling in the event of a chain failure while still allowing the release of the gear in an emergency **(Figure 6)**.

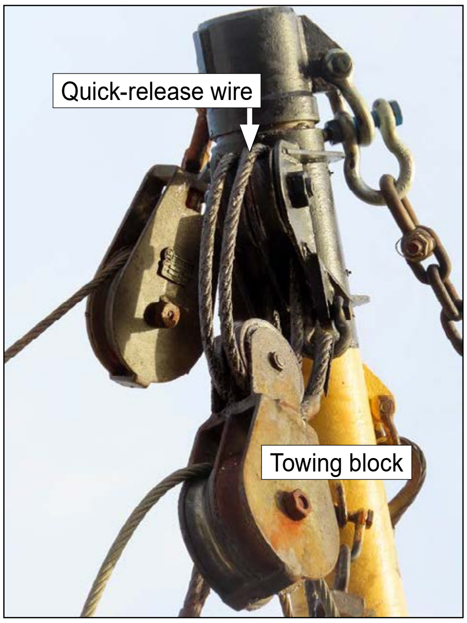


**Figure 4:** Quick-release arrangement with derrick head quick-release wire and sheave

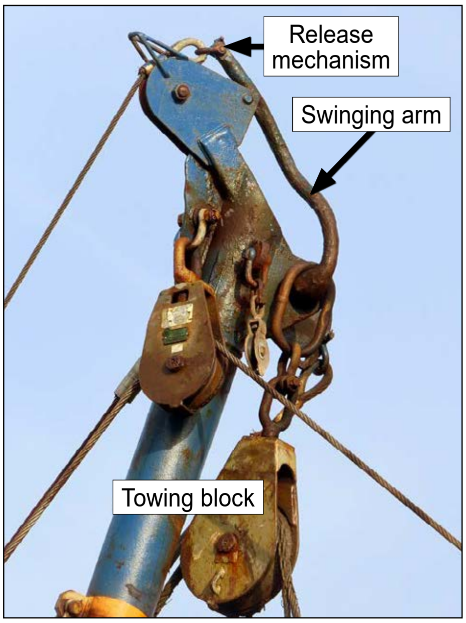


**Figure 5:** Quick-release arrangement with derrick head swinging arm

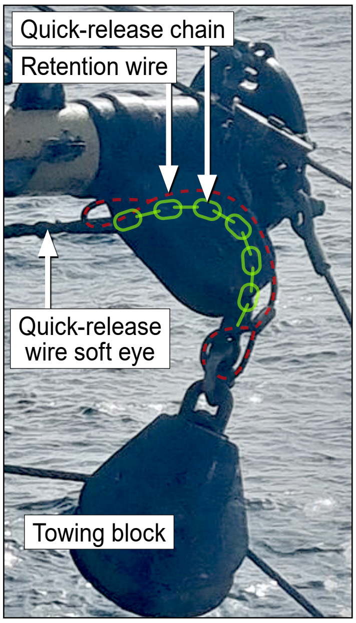


**Figure 6:** Quick-release arrangement with secondary means of gear retention

## SAFETY ISSUES

The initial stages of the investigation have identified that:

- The recent recorded accidents and failures of chain links leading over a static pin as part of a quick-release mechanism indicate the significant risk of such arrangements failing when loads are applied to the chains. These arrangements can induce complex loading forces in the chain links, leading to excessive wear on the chain links and significantly reducing the chain strength.

- The location of the chain links at the derrick head and the fact that the deterioration of the chain links may not be easily visible mean that it can be difficult to inspect and identify issues with the quick-release arrangement.
- The potential failure of chains used in this manner presents an unacceptable level of risk to crew members working on the deck below.

## RECOMMENDATIONS

The **Maritime and Coastguard Agency** is recommended to:

S2024/101 Conduct a focused inspection campaign on board UK scallop dredgers and beam trawlers fitted with derrick head quick-release mechanisms that incorporate chain to:

- raise awareness among skippers and crews of the significant hazards associated with the use of chain links passing over a static pin as part of the derrick head quick-release mechanism;
- confirm that the risk of a failure of the derrick head quick-release mechanism has been assessed, mitigated and documented by the owner, operator and/or skipper of the vessel; and
- verify that the crew has been informed of the findings of the risk assessment and the measures taken for their protection in the event of a failure of the derrick head quick-release mechanism.

**All owners, operators and skippers of UK scallop dredgers and beam trawlers that use chain as part of the derrick head quick-release mechanism on board their vessels** are recommended to:

S2024/102M Urgently ensure that a suitable and sufficient assessment of the risk of a failure of the derrick quick-release mechanism chain has been undertaken and documented, noting the safety issues identified in this safety bulletin, and that:

- mitigations are identified and immediately implemented to reduce the risk to the crew associated with a failure of the derrick quick-release mechanism to a level that is as low as reasonably practicable; and
- the crew are informed of the findings of the risk assessment and the measures taken for their protection.

Safety recommendations shall in no case create a presumption of blame or liability

**Issued February 2024**

**Annex E**

MAIB safety flyer to the fishing industry

MAIB

MARINE ACCIDENT INVESTIGATION BRANCH

# SAFETY FLYER TO THE FISHING INDUSTRY

## Fatal accident to a deckhand on board the beam trawler *Cornishman* (PZ 512), 44 nautical miles south-south-west of the Isles of Scilly, England on 6 February 2021

## Narrative

Image courtesy of Devon & Cornwall Police


*Cornishman*

At about 0630 on 6 February 2021, the crew of the beam trawler *Cornishman* were repairing the port trawl gear between fishing operations when the suspended steel trawl beam suddenly fell to the deck, striking and trapping a deckhand who was working underneath. The deckhand was declared deceased 1.5 hours later by the attending helicopter paramedic.

The investigation established that a 32mm Grade 8 chain link forming part of the port trawl gear's quick-release mechanism supporting the port beam had fractured and allowed the beam to fall. The chain was operated over a 150mm diameter fixed steel pin **(Figure 1)** at the top of the derrick; both the chain and its links were found to be corroded, heavily worn, and cracked.

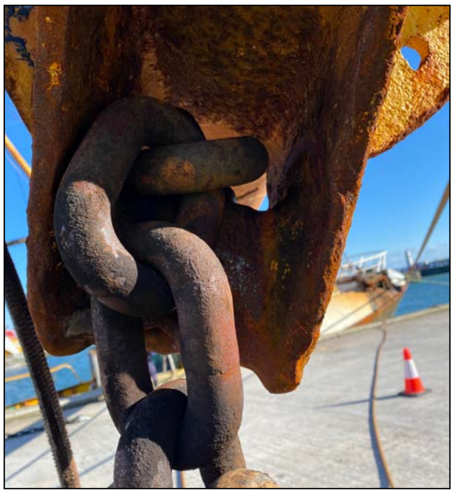

**Figure 1:** Quick-release chain over fixed steel pin

## Safety lessons

1. *Cornishman*'s chain over fixed pin arrangement resulted in side loading and bending stress of individual chain links due to the low ratio between the diameters of the 150mm fixed pin and the 32mm chain link, known as the D/d ratio **(Figure 2)**.

2. High alloy Grade 8 chains are not recommended for offshore use due to their susceptiblility to envrionmental cracking, resulting in loss of strength and risk of catastrophic failure while loaded.

3. Chains are primarily intended for straight line point-to-point loading. Where a change in direction is required a chain lifter, such as found on an anchor windlass, or a high D/d ratio arrangement is necessary.

4. The side loading of individual chain links on *Cornishman* resulted in out of plane stresses, which the chain was not designed to withstand. This caused heavy wear on the fixed pin and chain links as the links were operating under dynamic loads. Alternative quick-release designs are available and should be considered as a safety improvement to minimise the opportunity for sudden failure. A safety bulletin, issued by MAIB in February 2024, provides more details – https://www.gov.uk/maib-reports/safety-warning-issued-following-a-chain-failure-on-scallop-dredger-honeybourne-iii-with-loss-of-1-life

For illustrative purposes only: to scale

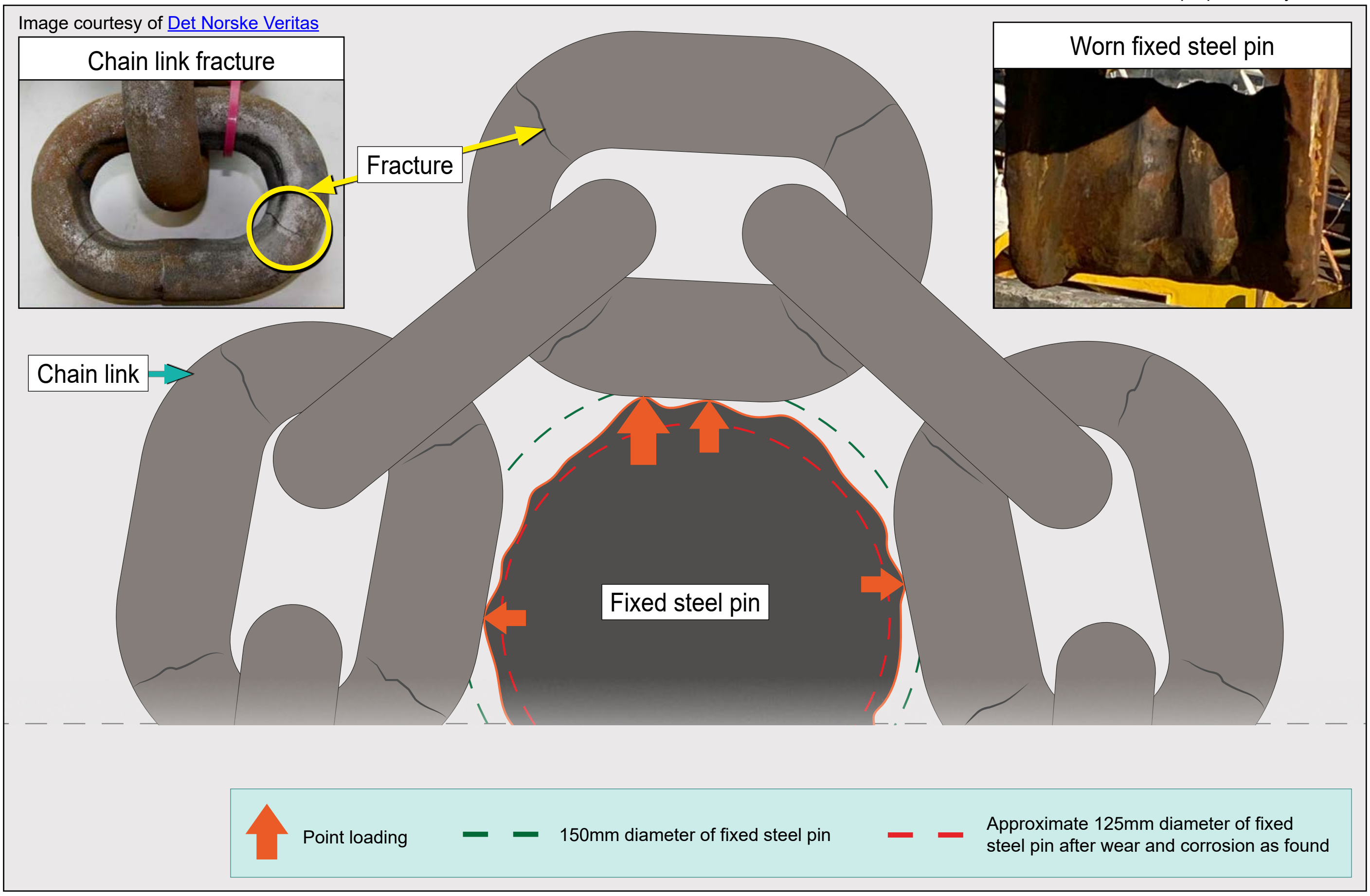


**Figure 2:** Representation of chain loading over fixed steel pin, showing links subjected to out of plane bending stress point loads

This flyer and the MAIB's investigation report are posted on our website: www.gov.uk/maib


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**Publication date: June 2025**


**Extract from The United Kingdom Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 – Regulation 5:**

"The sole objective of the investigation of an accident under the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012 shall be the prevention of future accidents through the ascertainment of its causes and circumstances. It shall not be the purpose of an such investigation to determine liability nor, except so far as is necessary to achieve its objective, to apportion blame."

**NOTE**

This safety flyer is not written with litigation in mind and, pursuant to Regulation 14(14) of the Merchant Shipping (Accident Reporting and Investigation) Regulations 2012, shall be inadmissible in any judicial proceedings whose purpose, or one of whose purposes is to attribute or apportion liability or blame.