Accident
Investigation Board
Norway

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REPORT JB 2013/01

REPORT ON RAILWAY ACCIDENT AT DOMBÅS STATION 13 JANUARY 2012, TRAIN 5701

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REPORT

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This investigation has been of limited scope. AIBN has therefore chosen to use a simplified report format. A full report is only used when required by the scope of the investigation. This simplified report throws light on the findings that were made and presents any safety-related recommendations.

Rolling stock:	
- Type and reg.:	TRAXX F 140 AC 2, number 119-003
- Production year:	2009
- Engine(s):	AC 3-phase asynchronous engines
Operator:	CargoNet AS
Date and time:	Friday 13 January 2012 at 22:44
Incident site:	Dombås Station
Type of incident:	Derailment
Type of transport:	Goods transport
Weather conditions:	Heavy snowfall
Light conditions:	Dark
Track running conditions:	Slippery
Number of occupants:	2
Personal injuries:	None
Material damage:	Locomotive and five wagons
Other damage:	Damage to infrastructure
Locomotive drivers (3):	Alnabru - Dovre / Dovre - Dombås (1) / Dovre - Dombås (2)
- Experience:	4 years / 25 years / 25 years
- Qualifications	All are authorised locomotive drivers
Sources of information:	Norwegian National Rail Administration, Bombardier, CargoNet AS, Norwegian Armed Forces Chemicals and Materials Laboratory Services, Norwegian Railway Authority (NRA)

1. FACTS

On Friday 13 January 2012 at 22:44, CargoNet AS freight train 5701 derailed at Dombås Station. There were two drivers in locomotive 1, and neither of these was injured in the incident. Train 5701 consisted of 2 locomotives and 16 wagons; see Figure 1. Locomotive number 2 and 5 wagons derailed at points no 3 at Dombås Station.

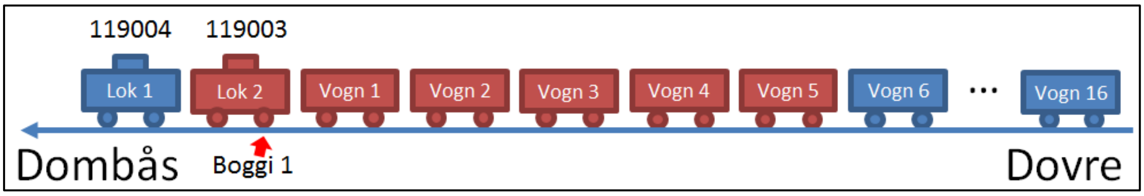


Figure 1: Train 5701; rolling stock that derailed is shown in red.

Prior to the derailment, there had been other problems with locomotive 2, registration number 119-003. This locomotive had been pulling wagons from Alnabru to Dovre, where it stopped because of a fault message. The driver explained that there had been some vibration in the locomotive at speeds over 60 km/h. The first fault message was noted at 17:02, and the train stopped at Dovre at approximately 17:06. The fault message in the locomotive indicated that there were problems with bogie no 1, which was the rearmost bogie in the direction of travel, see Figure 1. The problem was that this bogie was not receiving tractive power, and the train had to remain stationary, blocking any traffic past Dovre. With the assistance of the duty officer at CargoNet AS, the driver attempted to find the fault on the locomotive, but they gave up after a while. Locomotive number 119-003 still had tractive power to bogie 2, but was not capable of moving under its own steam. Heavy snow was falling that day, and this contributed to making the driving conditions difficult. The traffic controller agreed to allow passenger train 45 to help push freight train 5701 onto track 2 at Dovre. When train 5701 had been pushed onto track 2 at Dovre, the driver was relieved at about 19:00.

Figure 2: Locomotive no 119-003.

Figure 3: Derailed wagons.

At about 21:35, an extra locomotive, number 119-004, arrived at Dovre, in order to pull the train to Trondheim. After the train was connected and the brakes tested, it was given clearance from the traffic controller to proceed north towards Trondheim. Shortly after the train left Dovre, the driver was contacted by the traffic controller, who reported an alarm signal from points 2 after the train had passed. The 'fault in points' alarm message can indicate a derailment, and the train was stopped immediately. The driver then made an external examination of the train in deep snow, but could not find any kind of irregularities. The driver contacted the traffic controller and reported the results of the investigation, and was given the go-ahead to continue.

At 22:44, the train arrived at Dombås Station, and just as the train passed points no. 3, the drivers felt the locomotive jerk, and heard a bang. At that point, the train had separated between locomotive 119-004 and locomotive 119-003, and the derailment had occurred.

2. INVESTIGATIONS CARRIED OUT

The AIBN was notified of the incident on 13 January at 23:30, and arrived at Dombås with three accident investigators on 14 January at 06:00.

The parties involved were notified by a letter of 25 January that an investigation would be initiated, and the European Railway Agency (ERA) was notified of the accident on 25 January 2012.

Upon arrival, the AIBN was informed by the Norwegian National Rail Administration (NNRA) that it had discovered damage to a section of track before Dombås Station. The 16 km long section from Brennhaug to Dombås was inspected, in order to document the damage along the track.

Table 1: Overview of damage to infrastructure

Object	Km	Description	Map
A - Level crossing	326.522	The first traces in the snow were observed 15 metres after the level crossing.	
B - Centre of tracks	326.610	Gravel had been scattered onto the snow, a sign that something had disturbed the ground between the tracks.	
C - Level crossing	326.850	Wooden panel on level crossing was damaged and had been moved 5 to 10 cm northwards.	
D - Bridge	327.900	Small cracks were observed in the guide rail at the bridge.	
E - Points 1 Dovre	330.281	Clear traces in the snow that something was hanging too low under the train, and more obvious traces where it had moved onto track 2.	
F - Points 2 Dovre	331.976	Damage to left blade, and a metal fragment from the lower part of the engine of number 119-003 was found in the track.	
G - Hjelle level crossing	340.490	Damage to Strail panels. The panels became caught on the train, and these fell off along the track. The bolt for the emergency support was found just north of the level crossing.	
H - Points 1 Dombås	342.570	Extensive damage.	

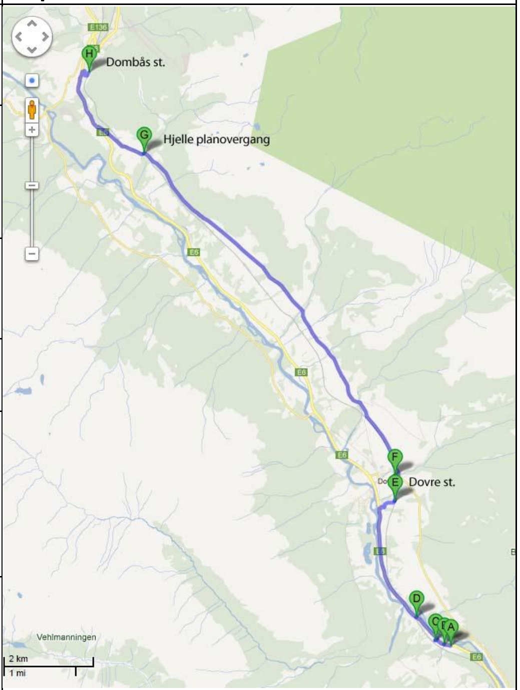


Figure 4: Map of findings (source: Google maps)

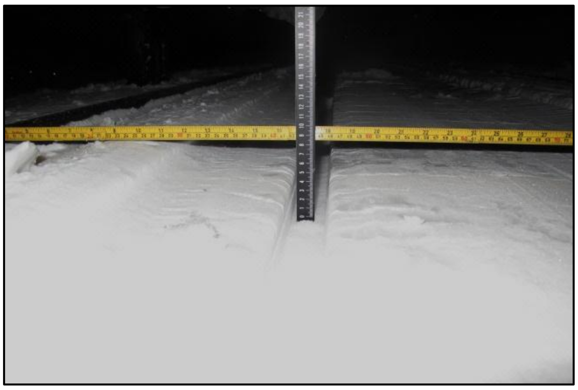


Figure 5: Traces in the snow - Finding E.

Figure 6: Strail panel at Hjelle level crossing finding G

After the track was examined, locomotive number 119-003 was examined. This examination confirmed that the torque link and the emergency support for engine 2 on bogie 1 were broken.

Figure 7: Bogie 1 of locomotive 119003

Figure 8: Broken torque link (1) and emergency support (2)

The locomotive was examined at Grorud repair shop on 23 January by representatives from the AIBN, CargoNet AS and Bombardier, the manufacturer of the locomotive. The torque link and emergency support were removed and sent to the Norwegian Armed Forces Laboratory Services for examination. On 25 January, the body of the locomotive was lifted off the bogies, revealing traces of arcing and damage to the cables to the engine that had broken loose.

2.1 Legislation and regulations

International requirements relating to the responsibility for placing rolling stock in service are regulated by Article 14 of Directive 2004/49/EC (the Railway Safety Directive), and by Directive 2008/57/EC (the Railway Interoperability Directive), among other things.

The Norwegian Rolling Stock Regulations are national regulations containing requirements that rolling stock must satisfy before permission can be granted to place them in service pursuant to the Norwegian Interoperability Regulations and requirements for railway undertakings relating to the operation and maintenance of rolling stock. The regulations entered into force on 1 July 2012, but the items listed below were previously regulated by the [Norwegian Railway] Safety Regulations.

- Section 4 'Overall responsibility for safety' contains the following wording: *'The railway undertaking shall ensure that the rolling stock is in a condition that facilitates safe operation of the rail system at all times. The technical design and operational condition of rolling stock shall be such as to ensure an acceptable level of operational risk.*'

- Point 1.4 in the Annex states that *'Documentation must be in place that each vehicle has been tested on the track so that it is able to withstand the operational and climate loads it will be exposed to during operation, including anti-derailment safety, satisfactory running properties in the speed class for which the rolling stock is designed and braking action.'*

- Point 2.1.1 in the Annex states that *'The vehicle must have sufficient mechanical strength and integrity to withstand the forces to which it will be exposed in all expected modes of operation over its service life.'*

- Point 2.1.7 in the Annex states that *'Connections between different parts of the vehicle, for example the vehicle body and the bogie, must be capable of withstanding the static and dynamic loads to which they are exposed. For load situations and strength calculations, the following standards are accepted: EN 12663, UIC 577, ERRI B12/RP17, UIC 515-1 and UIC 615-1.'*

- Section 7. Operation, inspection and maintenance of rolling stock Requirements of the railway undertaking relating to responsibility, operation, maintenance, inspection, minimum safety requirements etc.

Section 2-3 of the Safety Regulations state that *'The railway enterprise shall have barriers in place that reduce the probability of escalation of faults and danger and accident situations. The barriers must be identified, and the established barriers and their functions must be known throughout the organisation. If more than one barrier is required, they must be sufficiently independent of each other.*

One example of an area in which the regulations describe a barrier function, is the Vehicle Regulations' Annex 10.1.2.4 on fire walls, which contains a reference to TSI LOC & PAS[1] point 4.2.10.5 (2011/291/EU). The latter also includes guidelines from the European Railway Agency explaining the purpose of barriers and references to other accepted measures such as early detection.

With respect to standardisation work, the Norwegian Railway Authority (NRA) informs us that it is primarily a task for the industry, and that such standards are developed by the industry itself. In Norway, it is the requirements set out in railway legislation that apply, and they include overriding general requirements of relevance to the present context. The railway legislation also contains international requirements; one example is the Norwegian Rolling Stock Regulations, where much of the content is taken from or refers to other sources. Concerning the level of detail in railway legislation and international

[1] Annex to Decision 2011/291/EU. Technical specification for interoperability relating to the rolling stock subsystem —

requirements, these are meant to be minimum requirements. The idea is that one should not be bound by a specific solution, but enjoy flexibility within safe and expedient limits.

2.2 Previous incidents with locomotive number 119-003

The locomotive had previously derailed at Dalane Station on 31 January 2010 with the same bogie as in this investigation; see previously submitted investigation report JB 2010/05. On that occasion, the locomotive collided with a buffer stop and derailed with bogie 1. Bogie 2 remained on the track. The derailment resulted in damage to the plough and buffers, as well as some damage underneath the locomotive. CargoNet AS carried out the repairs after the derailment, and the locomotive was back in operation in early May 2010.

After it had driven 3,246 km, a fault on the locomotive was reported on 15 May 2010, which proved to be a broken transmission. The bogie and transmission were then sent to Bombardier in Germany to be repaired. Bombardier has informed us that, at the time when the bogie and transmission were repaired, it was not aware that the locomotive had derailed at Dalane two weeks previously. The torque link was visually checked and approved for further use. The 2010 repair log explains that the transmission was damaged and did not contain any oil [1]. Damage was noted on bogie 1 on axles 1 and 2, the worst damage being on the transmission for axle 2. This is the same place as the breakage to the torque link occurred in the present investigation (axle 2/engine 2). The damage to the transmission for axle 1 is consistent with a collision between the locomotive and an object in the track; see Figure 9. However, the damage to the transmission for axle 2 does not appear to be related to a collision with an object; see Figure 10. The damage was not at the lowest point on the transmission, and the marks appear to have been made under high load and at very low speed. This suggests that the damage to the transmission had occurred in connection with the derailment at Dalane or during the salvage operation. CargoNet AS and Bombardier agree that the damage to the transmissions seems to be related to the derailment at Dalane, and the AIBN has therefore not looked into this in any detail.


Figure 9: Marks on axle 1(Source: CargoNet AS) Figure 10: Marks on axle 2 (Source: CargoNet AS)

2.3 Recording unit

A little less than four kilometres from Dovre, overcurrent was registered on bogie 1 at 17:02. The GPS position of this data corresponds to object A in Table 1. At that time the speed of the train was registered at 74 km/h. At 17:03, the recorded data showed that there were disruptions to the current sensor MGr1, and the train's computer initiated protective action and deactivated the power supply to bogie 1. The train's speed was 60 km/h when the power supply to bogie 1 was deactivated. Between 17:04 and 17:05, the driver attempted to restart the converter several times, but the protective action prevented this. The train's speed was decreasing. At 17:05:29, the train's speed was 29 km/h and, at 17:06, the train had come to a standstill at Dovre. This corresponds with object E in Table 1.

2.4 Metallurgical examinations at the Norwegian Armed Forces Laboratory Services

The AIBN used the Norwegian Armed Forces Laboratory Services to examine the torque link and emergency support of locomotive 119-003: see Figure 11 and figure 12.
The Norwegian Armed Forces Laboratory Services concluded that the torque link did not show any signs that it had been underdesigned [2] [3]. This was based on the fact that the damage had mainly occurred during high-cycle fatigue[2] and that the extent of the final fracture (overload) was negligible. The report also indicates that the torque link could have been subject to shock loads[3] in the two incidents described earlier (derailment at Dalane and collision damage to the transmission). It is possible that these overloads caused local stress deformations[4] in the component and contributed to the initiation of fatigue damage. The report is unable to establish with any certainty that the shock loads alone were the cause of the fracture initiation. The report also shows that micro-cracks could be observed in the surface of the engine support in the area of crack initiation, and that these are related to the forging process. The Norwegian Armed Forces Laboratory Services recommend improving how the surface is treated after forging, in order to improve the component's properties.

Since crack propagation had been going on for some time, the Norwegian Armed Forces Laboratory Services believe that it could have been detected during maintenance, if this had been conducted at suitable intervals and if suitable procedures had been followed.

Furthermore, the examination showed that the emergency support had a fatigue crack as a consequence of the loads to which it was subjected after the torque link failed; see Figure 12. The loads on the support were considerable, since the final 30% of the crack surface is due to overloading.

Figure 11: Torque link examined.

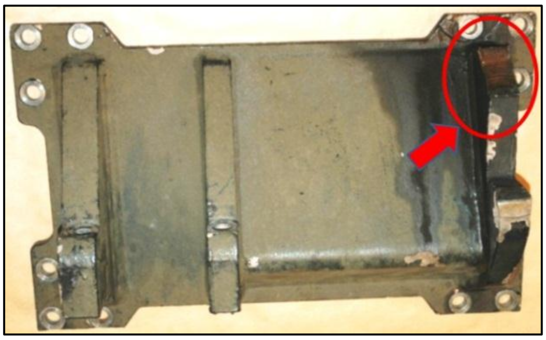


Figure 12: Emergency support examined.

[2] Many cycles before fracture, typically more than 10^4 stress cycles. The cycles can, for example, be in the form of vibrations.
[3] In this context, it is possible that the derailment at Dalane in 2010 or the damage to the transmission resulted in shock loads.
[4] Local stress deformations can occur in an unintended area of the tube, as a consequence of geometrical changes, shock loading or overloads.

2.5 Inspection and maintenance of torque link and emergency support

Bombardier's description of maintenance for the locomotive contains the following instructions for the torque link and emergency support: 'The torque link and emergency support should be inspected for integrity and to ensure that they are undamaged'. The shortest maintenance interval before the derailment was every 15,000 km. The total recorded distance travelled by locomotive number 119-003 was 356,951 km, and before the derailment at Dombås, it had travelled 3,460 km since the most recent maintenance.

Effektfortegnelse **BOMBARDIER**

Lok-nr.: TRAXX F 140 AC2 (DASN)

IN	15.000 km	I 1	150.000 km	I 3	600.000 km	R 2	2.000.000 km / 8 år
IN - 1	30.000 km	I 2	300.000 km	R 1	1.000.000 km / 4 år	R 3	4.000.000 km / 16 år

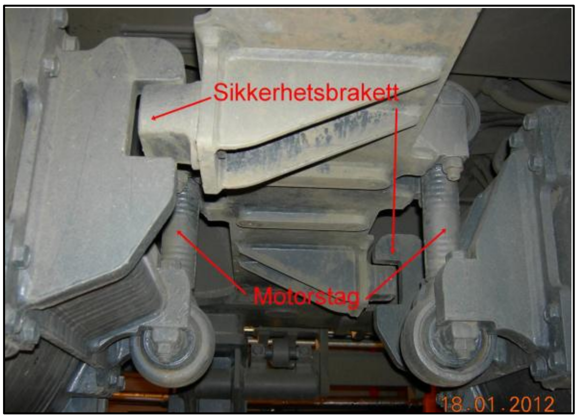
Kap.-nr.	AKTIVITET	IN	IN - 1	I 1	I 2	I 3	R 1	R 2	R 3
6.9.3	**Drivmotor**								
	Visuell kontroll for utvendige skader	x	x	x	x	x	x	x	x
	Ettersmør rullelager B-side				x	x	x		
	Motor demonteres, rengjøres og testes							x	x
	Visuell kontroll for slitasje og skader							x	x
	Gjennomfør elektrisk kontroll av statorvikling							x	x
	Skifte rullelager B-side							x	x
	Montere motor							x	x
6.10	**Trekkrafttilkobling**								
	Kontroller at tog-trekkstangen sitter fast	x	x	x	x	x	x	x	x
	Nødoppheng (fangliner) inspiseres	x	x	x	x	x	x	x	x
	Inspiser ringelementer for skader			x	x	x	x		
	Skifte ringelementer							x	x

Figure 13: Maintenance schedule [4].

CargoNet AS has its own check-lists for each scheduled maintenance, and these include the items from Bombardier's maintenance schedule. CargoNet AS advises that its engineers are instructed to use the maintenance instructions in combination with the check-list. Information about how to handle the locomotive is also in the locomotive's type manual and in the drivers' type training. Serious faults should be listed in what is known as an 'A-fault list'.

There are no standards or regulations specifying how to design and inspect emergency supports. Bombardier has informed the AIBN that ascertainment of whether the emergency support was in use, was based on the assumption that such use would cause the emission of loud, unpleasant noise that would be detected by the driver. The derailment at Dombås showed that this was not the case.

After the derailment at Dombås, CargoNet AS has introduced more frequent and detailed inspections of torque links and emergency supports. This is described in more detail in section 3.



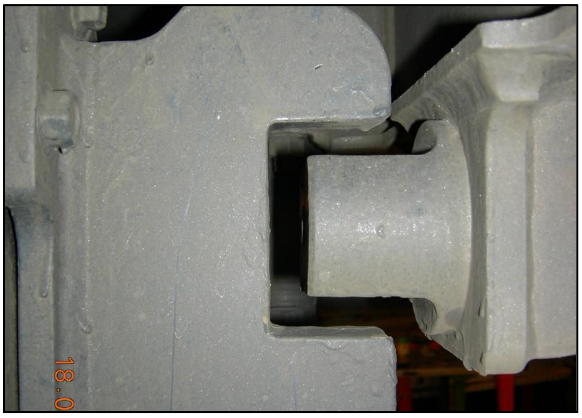


Figure 14: Torque links and emergency supports [5]. *Figure 15: Emergency support [5].*

2.6 Vibrations on CargoNet AS 119 locomotives

CargoNet AS informs the AIBN that higher vibrations than normal have been observed in several of their TRAXX locomotives. Frequent wheel turning and wheel replacement has been required on CargoNet's TRAXX locomotives. In some instances, this has been required twice as often as on other locomotives. It is normal for unwanted vibrations to occur when a wheel is approaching the time when it will need to be turned or replaced. On its part, Bombardier ascribes this to the harsh winter conditions in Norway, and high utilisation of traction power in CargoNet AS operations compared with other locomotives. According to Bombardier, this is a problem that has only been identified in Norway. It is related to wheels that are out-of-roundness, and these have, in turn, caused problems with vibrations in bogies.

Bombardier has carried out measurements of the track in Norway, in order to identify the loads to which the locomotives are subject and any deviations in relation to track measurements in other parts of Europe [6]. On the first test runs, unexpected loads were observed that could not be ascribed to any known phenomenon on the TRAXX locomotives. The tests resulted in a number of abnormal values that proved to be due to out-of-roundness wheels on the locomotive that was being used for the measurements [7]. According to Bombardier, wheels have never been reported to be out-of-roundness in the TRAXX rolling stock, which currently includes more than 1,000 locomotives.

Bombardier has also carried out measurements on the turning machine at Lodalen, used for turning the wheels of the TRAXX locomotives. It did this because there are no reports of similar vibrations in other parts of Europe in which TRAXX locomotives are being used. Bombardier says that the provisional results of the measurements indicate that the turning machine is not capable of restoring complete roundness to faulty wheels. CargoNet AS claims that it has not been demonstrated that the turning machine introduces faults to the wheels, and it has reported vibrations and out-of-roundness even in wheels that are completely new.

Bombardier has carried out comparative measurements in a similar turning machine in Sweden. The TRAXX locomotive that was used for the purpose is used in a corresponding manner to the locomotives in Norway. Neither before nor after turning, were there any signs of out-of-roundness in the wheels.

The second measurement of the track was carried out using a locomotive whose wheels had recently been turned. The measurements showed that the load on the track was on a par with other European countries, which, according to Bombardier, confirms the assumptions used in designing the locomotive.

This was something that Bombardier was still in the process of clarifying at the time this report was written.

In September 2011, Eisenbahn-Bundesamt (the railway authority in Germany) issued a safety warning[5] about vibrations in TRAXX locomotives as a consequence of torsional forces between axles and wheels. This is a separate problem, in which torsional oscillations arise that can overload the axles when wheelslip is not brought under control as a result of faulty speed sensors. There have been no faults with the speed sensor of locomotive number 119-003.

The Norwegian Railway Authority informs that TRAXX locomotives have what is known as a ‘limited operating licence’ in Norway. This means that the locomotive has not received final approval for use in Norway. Among the points that remain outstanding is a Bombardier report in response to the requirement for clarification of safety-factor calculations on wheels and axles in relation to torsional forces.

2.7 Examinations carried out by the manufacturer Bombardier

Bombardier carried out several examinations and tests of the torque link and emergency support of the locomotive series that was involved in the derailment. It carried out static and durability tests of used and new torque links, as well as data simulations in order to identify any weak points in the emergency support. It also carried out load measurements and material tests. The examinations and tests did not manage to recreate the break in the torque link that was discovered after the derailment at Dombås. The torque link has been used for more than 16 years, and more than 1,000 TRAXX locomotives have this type of torque link. According to Bombardier, there have been no previous reports of similar faults in the torque link.

2.7.1 Material analyses

Material tests of the torque link were carried out in the area around the bearing eye in which the rubber bearing sits [8] [9]. The values of the chemical composition, microstructure and hardness values are in line with relevant standards, and have the necessary tensile strength. This was also confirmed in the Norwegian Armed Forces Laboratory Services' report [2].

2.7.2 Static tests

Five static tensile tests were carried out on torque links until they broke; see Figure 16. Each time, the break occurred in the torque link's tube, and not in the area around the bearing eye, which is where the break occurred in the derailment at Dombås in 2012 [10]. The loads used to break the torque link are in line with the calculated loads it is designed to tolerate.

[5] European Railway Agency (ERA) - Safety Information System (SIS). SIS provides a platform which the EU's national railway authorities and the national accident investigation boards use to share safety-related information.

2.7.3 Durability (fatigue) tests

Seven fatigue tests were carried out on torque links [10], during which none of the test samples failed in the same way as during the derailment at Dombås on locomotive number 119-003 in 2012; see Figure 18. This means that none of the samples suffered equivalent damage or breakage after running the same distance as locomotive 119-003. In five of the tests, cracks were observed in the area around the cut-in to the snap-ring of the rubber bearing in the torque link's bearing eye; Figure 19. This type of fault is a functional fault, and not a total failure of the torque link. It is a visible fault which has been covered in previous reports, and is expected to be discovered during maintenance. In two of the tests in which the torque link failed, the break was in the tube and not in the area around the bearing eye; see Figure 17. Calculations of the expected service life (in kilometres) of the torque link are based on fatigue tests and load measurements carried out on tracks in Switzerland [11]. These show that the kilometres travelled by locomotive number 119-003 were well within these values when it derailed at Dombås in 2012. Based on the Swiss track measurements, it is estimated that functional faults can be expected after 8.28 million kilometres, and total failure after 51 million kilometres.

Figure 16: Static tests [10].

Figure 17: Break in tube during durability test 4 [10].

Figure 18: The test rig [10].

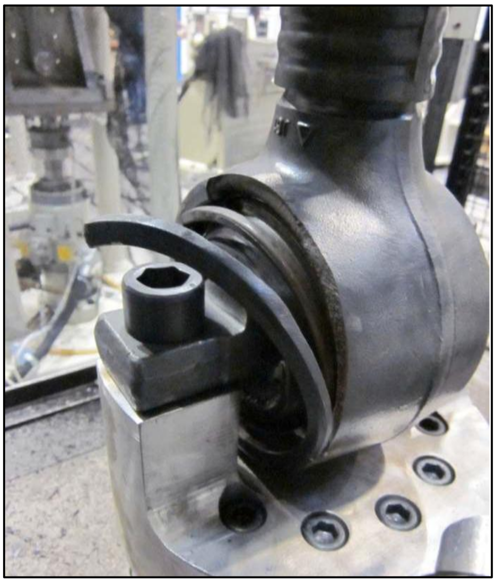


Figure 19: Cracks in ring around the bearing [10]

2.7.4 Analysis of residual stresses

Residual stress analyses were carried out in the area identified as the crack initiation area on 119-003's torque link [12]. Two torque links that had travelled the equivalent number of kilometres as the number 119-003 locomotive were used, and one new, unused part. The residual stresses were found to be the same in the used and new parts. Bombardier claims that this demonstrates that the loads on the torque link are not great, because if they were, the residual stresses in the used parts would differ from those in the new parts. It is also a known fact that compressive stresses usually do not lead to crack formation.

2.7.5 Tests of surface cracks on torque links

Crack tests were carried out on 11 used torque links from CargoNet AS's locomotives. This is equivalent to 25% of all the torque links on the ten locomotives in CargoNet AS's fleet [8]. Crack tests were also carried out on the seven torque links that were used in the fatigue tests. No cracks were found in any of the 18 samples.

2.7.6 Track measurements in Norway

Bombardier states that it is conducting new track measurements in Norway, in order to check that the design of the torque link is adequate. When the results of the measurements are available, it will calculate expected service life, in order to verify that the loads from tracks in Norway are comparable with those in Switzerland.

2.7.7 Analyses of emergency support

The emergency support was plotted into a finite element method[6] (FEM) analysis, and strength analyses were performed [13][14]. The results of these showed that the weakest point on the emergency support was the bolt and the washer behind the bolt [15]. The design of the rest of the emergency support was considered to be adequate.

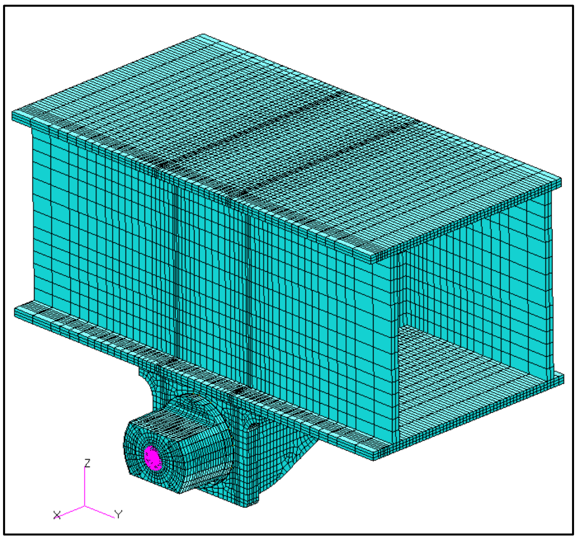


Figure 20: Emergency support bogie-side[13].

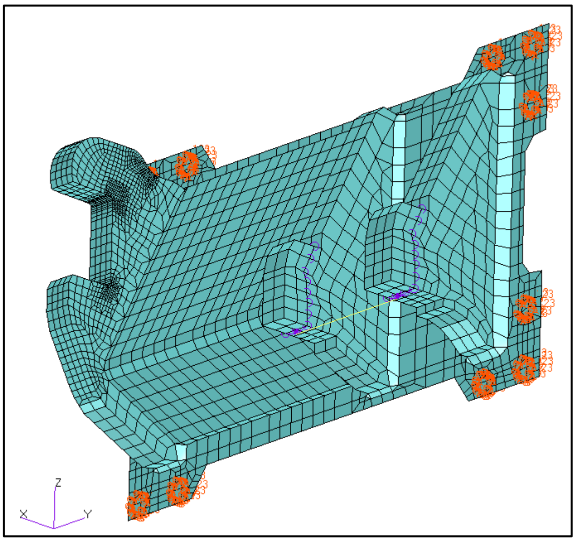


Figure 21: Emergency support engine-side [14]

[6] Method in which software is normally used to analyse various structures and perform strength analyses.

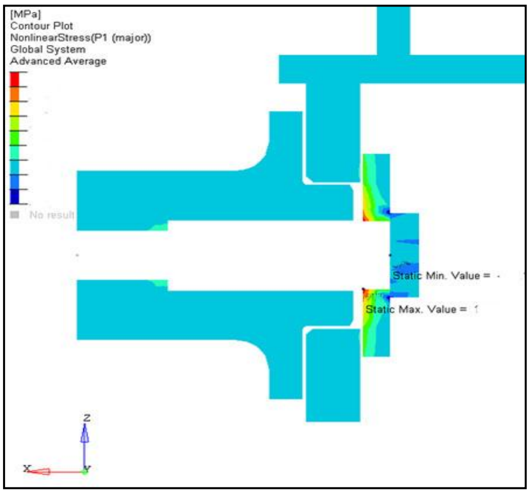


Figure 22: Strength analyses of bolt and washer [15].

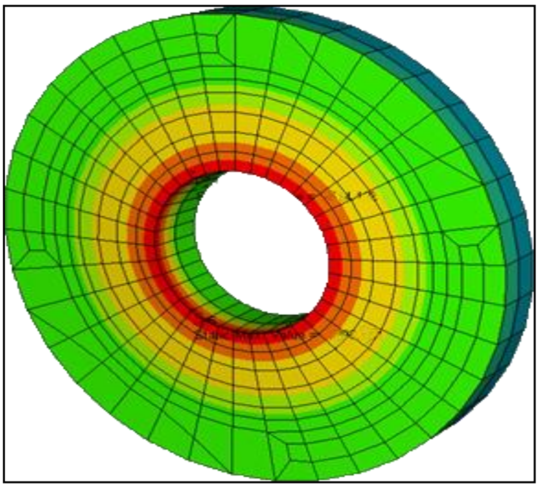


Figure 23: Strength analyses of washer [15]

The Norwegian Armed Forces Laboratory Services prepared an estimate of the number of crack arrest lines on the engine side panel's crack surface [16], and concluded that there were approximately 50 crack arrest lines on the emergency support's crack surface. The conclusions were sent to Bombardier for an assessment of the loads to which an emergency support is subjected, and an estimate of how long the emergency support was in use before it broke. Bombardier had not prepared this estimate at the time this report was written.

2.8 Similar incidents

There are similarities between the derailment at Dombås on 13 January 2012 and a derailment at Dombås in 2006.

On Tuesday 12 December 2006, a CargoNet AS freight train derailed with two wagons at Dombås Station because of a broken spring; see report JB 2008/03. The wagons that derailed at Dombås were owned by Autolink AS, and it was discovered that these had been involved in a previous derailment in July 2006. It transpired that the repairs after the derailment in July 2006 had been inadequate, and that a damaged spring had not been discovered and therefore not replaced. Among the recommendations put forward in the AIBN report was safety recommendation 2008/06T, stating that safety inspections after a derailment of rolling stock should be improved. The Norwegian Railway Authority followed up on this recommendation, which has now been closed. The background for closing the item was that '*the railway undertakings can demonstrate that safety has been satisfactorily improved in terms of checking safety-critical components on rolling stock after a derailment. Some railway undertakings changed their internal procedures as a consequence of this safety recommendation*'.

3. MEASURES PLANNED AND MEASURES IMPLEMENTED

In a letter of 19 January 2012, the Norwegian Railway Authority requires operators of TRAXX locomotives to report on how they handle faults and how they perform checks and inspections of drive gear and components in terms of discovering cracks and crack growth. At the moment, TRAXX locomotives are temporarily approved for operation in Norway until April 2013.

On 31 January 2012, Bombardier sent a letter to its clients, recommending that they replace any torque links that showed any damage to the metal sheets in the bearing. It also recommended that the torque link be replaced if a locomotive had been involved in an incident such as a derailment, or had been subjected to similar loads that had caused structural damage.

CargoNet AS has changed its inspection procedures after the derailment at Dombås, and now requires drivers to check the emergency support during their pre-trip and post-trip inspections. More detailed descriptions have been drawn up for maintenance personnel, detailing how to inspect torque links and emergency supports using an appropriate NDT[7] method. The frequency and level of detail of torque link and emergency support inspections have also been increased with the extra winter inspection at 7,500 km.

Bombardier has decided to make the torque link and emergency support of a sturdier construction on its TRAXX locomotive.

4. THE ACCIDENT INVESTIGATION BOARD NORWAY'S ASSESSMENTS

The results of the examinations of the torque link and emergency support substantiate the theory that the engine of locomotive number 119-003 had been supported by the emergency support for some time without this having been discovered either by drivers or maintenance personnel. The emergency support is the final safety barrier preventing the engine from falling onto the track, and that is why it is so important from a safety point of view that situations in which the emergency support is performing its function are discovered in time. The inspection and maintenance procedures that applied to inspection of torque links and emergency supports before the incident did not provide sufficient guidance either to drivers or maintenance personnel to enable them to discover and rectify a broken torque link before this also resulted in a broken emergency support.

The inspection and maintenance schedule was supplied by the manufacturer Bombardier at the same time as the locomotive. One important element in this kind of inspection and maintenance schedule is how use of a final safety barrier should be discovered/detected. The supplier must therefore be responsible for providing a specific list of final safety barriers, and how their use may be discovered. In this instance, the assumptions regarding how personnel would discover that the emergency support was in use were incorrect. Bombardier states that it had assumed that drivers would notice that an emergency support was in use, since it assumed that there would be a lot of noise and knocks. If the assumptions regarding a barrier are incorrect, it will be difficult for operators using the material to discover this for themselves. It must also be based on previous experience in Norway. The AIBN believes that CargoNet AS is responsible for carrying out a risk assessment of the maintenance schedule supplied with the locomotive, but that this must be viewed in the context of CargoNet AS's operations.

Shortly after the derailment, CargoNet AS introduced more frequent and detailed inspection and maintenance of torque links and emergency supports for this type of locomotive. It did this because after the derailment, there was uncertainty regarding the

[7] NDT – Non Destructive Testing.

design of the torque link and the emergency support. This means that drivers must inspect the emergency support as part of their pre-trip and post-trip inspections, and also that maintenance personnel have received a more detailed description of how to check these parts.

Before the locomotive derailed at Dombås, it stopped at Dovre, where the onboard computer warned that there were problems with bogie 1, and that the bogie had been disconnected as a result of the fault. With the assistance of the CargoNet AS's duty officer, the driver tried to find out what had caused that fault message, but they had no descriptions or training to suggest that the fault message had anything to do with a loose engine. As part of the more frequent and detailed inspection and maintenance of emergency supports after the derailment, the C Circular instructs drivers that: 'if abnormal sounds or repeated fault messages occur during operation, and if these can be related to bogies or engines, a visual inspection must be carried out, as described above'.

The AIBN believes that the supplier, Bombardier, should assess whether it should include more detailed guidelines or information on how to detect faults connected with the emergency support, if personnel receive similar fault messages to those that occurred before the derailment at Dombås.

The AIBN believes that it would have been possible to discover that the engine was hanging loose on the locomotive at Dovre, if the driver had had sufficient training and instructions. The first attempt to find the fault was with the assistance of the traffic controller when the locomotive stopped at Dovre, but the fault was not discovered. After the traffic controller received a derailment indication, a visual inspection of the locomotive was then conducted. This inspection also failed to discover the fault. It was dark and there had been a great deal of snow on the day the locomotive derailed, which made the inspection of the locomotive very difficult. It is therefore important that drivers are sufficiently informed about how to carry out specific checks and inspections.

The tests and examinations carried out by Bombardier have not managed to recreate a broken torque link equivalent to that found on locomotive 119-003. No final fracture was discovered in the torque link, which suggests that some time may have passed since the original damage resulted in a fracture.

There are two possible explanations as to why crack propagation occurred in the torque link on locomotive 119-003. One is related to two previous incidents: the derailment at Dalane in January 2010 and the damage to the transmission that was discovered on 15 May 2010. The other is related to micro-cracks introduced during the forging process, which may have developed over time into a fracture.

The AIBN believes that the crack propagation most probably started as a consequence of shock loads. The damage that was found was the first reported case of this type of damage and it has not been possible to reproduce the same type of damage in connection with the investigation.

After the derailment at Dalane, the locomotive was repaired by CargoNet AS and had been in operation for approximately two weeks before damage occurred to the transmission. The repair was outsourced to Bombardier, and the bogie was sent to Germany for repair. The parts were repaired there, and the torque link was visually inspected and found to be in order. The inspection of the torque link was visual, and it is

very difficult, using this method, to detect small cracks or possible deformation of a torque link that is covered in black paint. However, it is clear that the torque link became considerably deformed (bent; see Figure 11) during the derailment at Dombås, and it would not have been possible to use such a badly bent torque link. It is unclear to what extent the torque link may have been damaged in the previous incidents, and whether such damage could be detected by visual inspection.
After the derailment at Dombås, Bombardier sent a letter to all its clients, stating that if a locomotive had been involved in a derailment or similar incident, it recommended replacing the torque link.

During the examination of the emergency support, it became apparent that the bolt and washer had been under-designed. This is consistent with the way in which the emergency support was observed to fail at Dombås. The AIBN believes that the best way to ensure safety in this connection is by establishing procedures to detect any failure in the engine's primary supports and to confirm, if applicable, that the engine is supported by the emergency support, and has therefore decided not to consider the design of the emergency support any further in this report.

Based on the frequency with which wheels have been turned and replaced, the TRAXX series appears to have been exposed to adverse vibrations in Norway. This may have propagated crack formation and subsequent breakage. It is natural for there to be some vibration before a wheel is turned or replaced. Vibrations are a contributory factor towards crack propagation, and the analysis from the Norwegian Armed Forces Laboratory Services showed that the crack propagation was of the high cycle fatigue type. Bombardier and CargoNet AS were working on this problem and trying to get to the bottom of it at the time this report was written. Bombardier advises that this is a problem that has not been reported by any of its clients other than CargoNet AS. The AIBN believes that it is important for Bombardier and CargoNet AS to focus on gaining control of these adverse vibrations.

The fault that triggered this incident was that the supplier, Bombardier, had not specified an inspection and maintenance schedule that was sufficient to enable detection that the emergency support was in use as the final safety barrier. This is related to the fact that, in its analyses, Bombardier had assumed that a driver would be able to hear or notice that the engine was being supported by the emergency support. There are no standards or regulations specifying how to design and inspect emergency supports. Both Bombardier and CargoNet AS have taken steps to deal with these matters since the derailment.

The AIBN believes that the problem is very difficult to detect, since it is apparent that the assumptions regarding a safety barrier are not correct. After the event, it is easy to see that the assumptions were incorrect, and that there must be a thorough review of the procedures for establishing and determining the conditions required to detect whether a safety barrier is in use.

Concerning the level of detail in the railway legislation and international requirements, these are meant to be minimum requirements. The idea is that one should not be bound by a specific solution, but enjoy flexibility within safe and expedient limits. Concerning the drawing up of requirements for emergency supports, both the Norwegian Railway Authority and the European Railway Agency consider such requirements to be too detailed for it to be expedient to include them in railway legislation or TSIs. The Norwegian Railway Authority informs us that, in its opinion, the requirements set out in the railway legislation are adequate to ensure that the engine does not drop. The incident has shown that several parties have failed to identify the risk relating to the emergency support and that there are around 1,000 locomotives of this type in Europe.

The AIBN is of the opinion that international standards should be developed for the emergency supports, which take account of both design and inspection/ detection that the emergency support is in use. Standardisation is primarily a task for the industry, and standards are usually prepared under the auspices of the manufacturers. An emergency support is a physical barrier to prevent an undesirable incident, and there must be mechanisms in place to detect that the barrier is in use. The requirements for emergency supports must be formulated so that they are functional. It must be possible to detect when such a support is in use and to repair the fault before an accident occurs. Those who carry out inspections and maintenance must have the requisite knowledge to determine whether the emergency support is in use.

5. SAFETY RECOMMENDATIONS

Safety recommendation RW no. 2013/01T

The first thing that failed before the train derailed at Dombås, was the primary support (torque link) for one of the engines. After that, the engine was held in place by the emergency support, which is the final barrier before the engine comes lose. After a while, the emergency support also failed, so that the engine dropped towards the track. The railway legislation requires documentation to be available of the vehicle having been tested on the track with respect to operational loads and anti-derailment safety. It is the railway undertaking CargoNet AS that has overriding responsibility for the safety of the rolling stock it uses. The manufacturer Bombardier is carrying out work on track measurements in Norway, and calculation of expected service life and loads on the torque links and emergency supports for the engines.

The AIBN recommends that the Norwegian Railway Authority follows up that CargoNet AS is able to document that the railway legislation's requirements are met as far as supports and emergency supports for engines are concerned, based on actual loads, including track power measurements carried out in Norway.

Accident Investigation Board Norway

Lillestrøm, 11. January 2013

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[5] 20 January 2012, CargoNet AS: C-circular no: 3/2012, revision 0

[6] 31. August 2012, Bombardier: Track measurement CargoNet 2012 – Data evaluation results.

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[13] 30 August 2012, Bombardier: Strength analysis of the emergency support at the bogie frame.

[14] 30 August 2012, Bombardier: Strength analysis of the emergency support at the motor bracket.

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[16] 20 September 2012, Norwegian Armed Forces Laboratory Services, analytical laboratory: Evaluation of crack arrest line distribution for ‘Engine side panel’ fatigue failure.

FLO/VEDL/FOLAT
Norwegian Defence Laboratories
Chemistry - Materials

Client	Technical Report
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Copy	

Title		
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1 Introduction

The Norwegian Defence Laboratories, Chemistry and Materials, was asked to assist in performing a failure analysis of a torque link and an engine side panel with fracture damages involved in a derailment at Dovre 13/01-2012. The received components are shown in Figure 1a-c.

The investigation involves fractography in SEM equipped with EDS, metallography and chemical analysis.

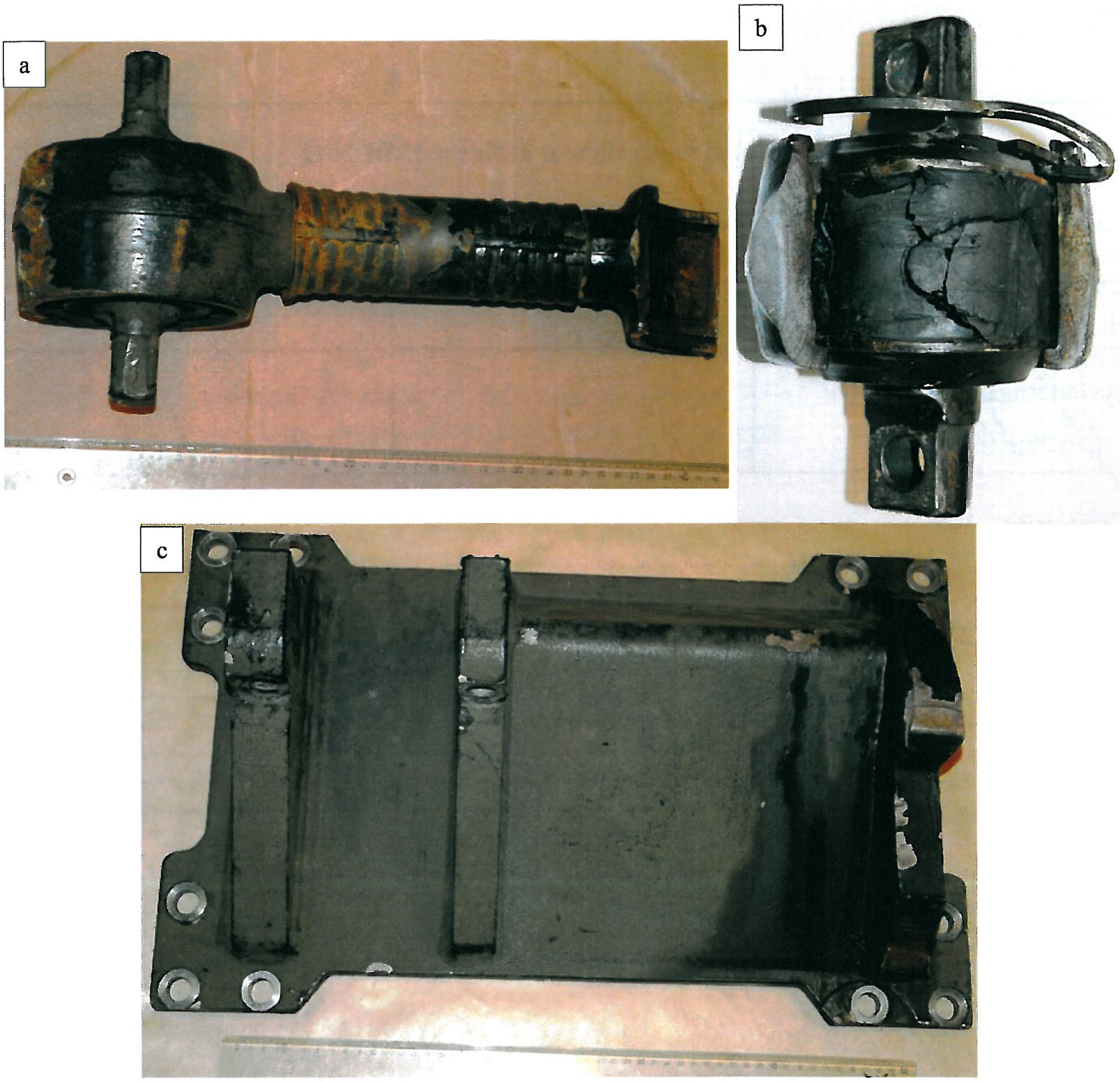

Figure 1a-b: Pictures of failed torque link. c: Picture of failed engine side panel.

2 Results

2.1 Analysis of failed torque link

2.1.1 Results

The fracture surfaces were cut out from the failed component as shown in Figure 2ab. A visual examination of the fracture surfaces revealed a large number of crack arrest lines often associated with fatigue. Based on the profile of the crack arrest lines, a probable crack initiation location was identified as shown in Figure 3. The initiation area was examined further in SEM equipped with EDS. The observations were that the crack initiations seemed to originate from the component surface. Irregularities associated with corrosion/pitting were not observed, see Figure 4. The two layers identified with EDS spectrums are most likely paint coating. Further characterization of the fracture surface in SEM reveals a corroded and contaminated surface (dust/sand), some eras showing a striated surface could also be observed; see Figure 5a-d.

In order to reveal possible secondary cracking adjacent to the observed failure, the paint was removed using light glass blasting. No additional crack initiations were observed as shown in Figure 6.

A metallographic sample was cut out from the component as shown in Figure 7a. The microstructure of the base material is shown in Figure 7b and reveals a ferrite perlite structure. Pictures of the sample towards the component surface reveal an irregular surface with micro cracks most likely originating from the forging process.

The chemical composition was established using mass spectrometry, and the alloy composition is summarized in Table 1.

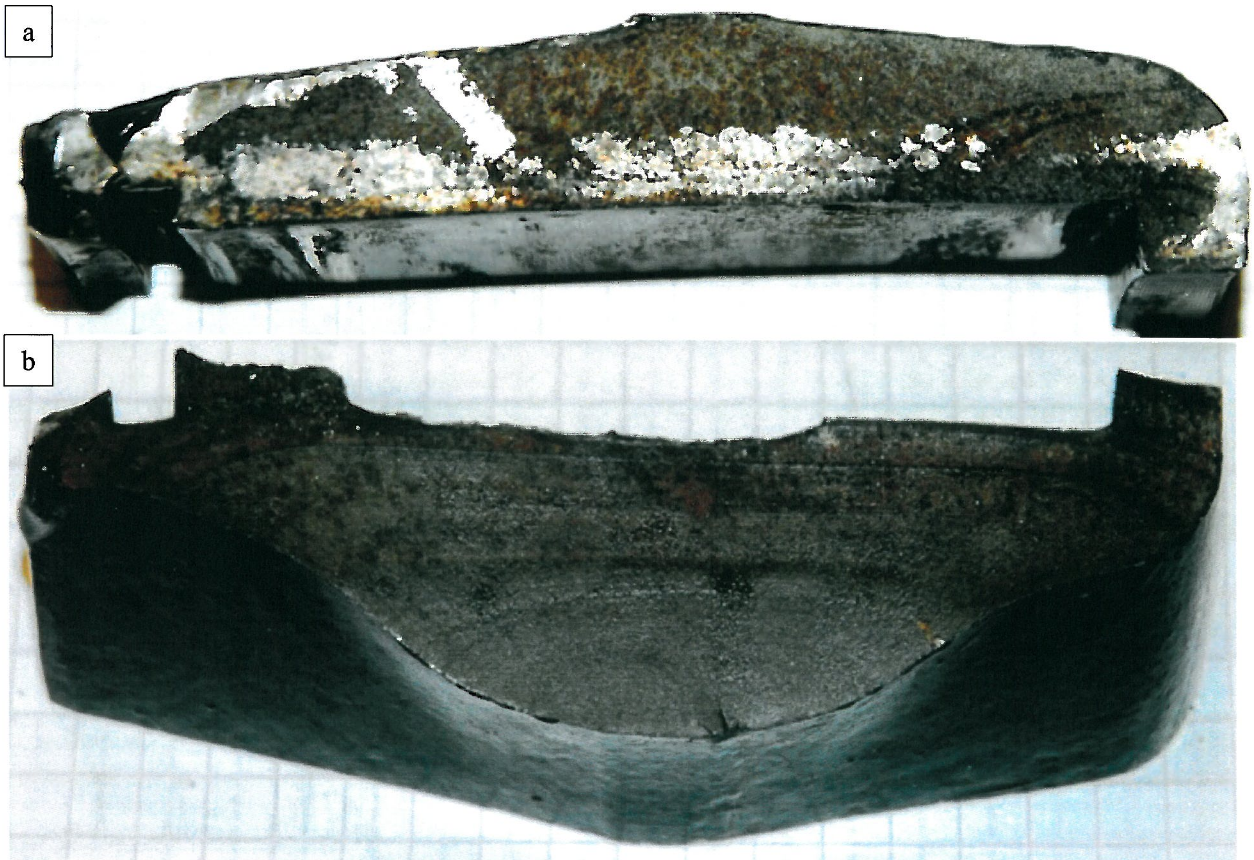

Figure 2ab: Fracture surfaces cut from the failed torque link.

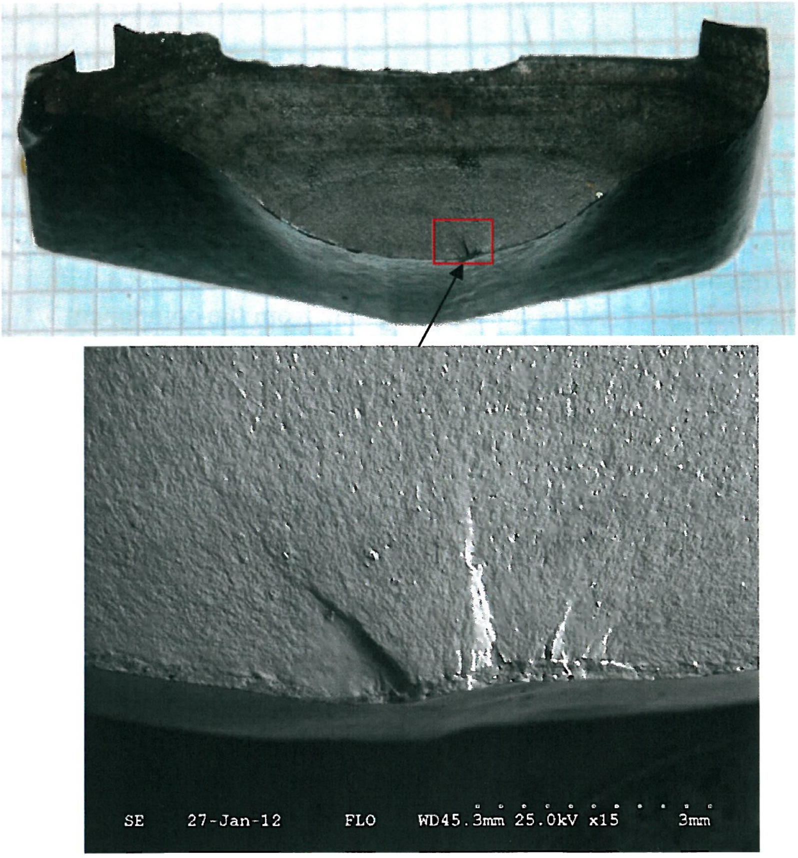

Figure 3 Location for probable crack initiation location based on crack arrest line orientations.

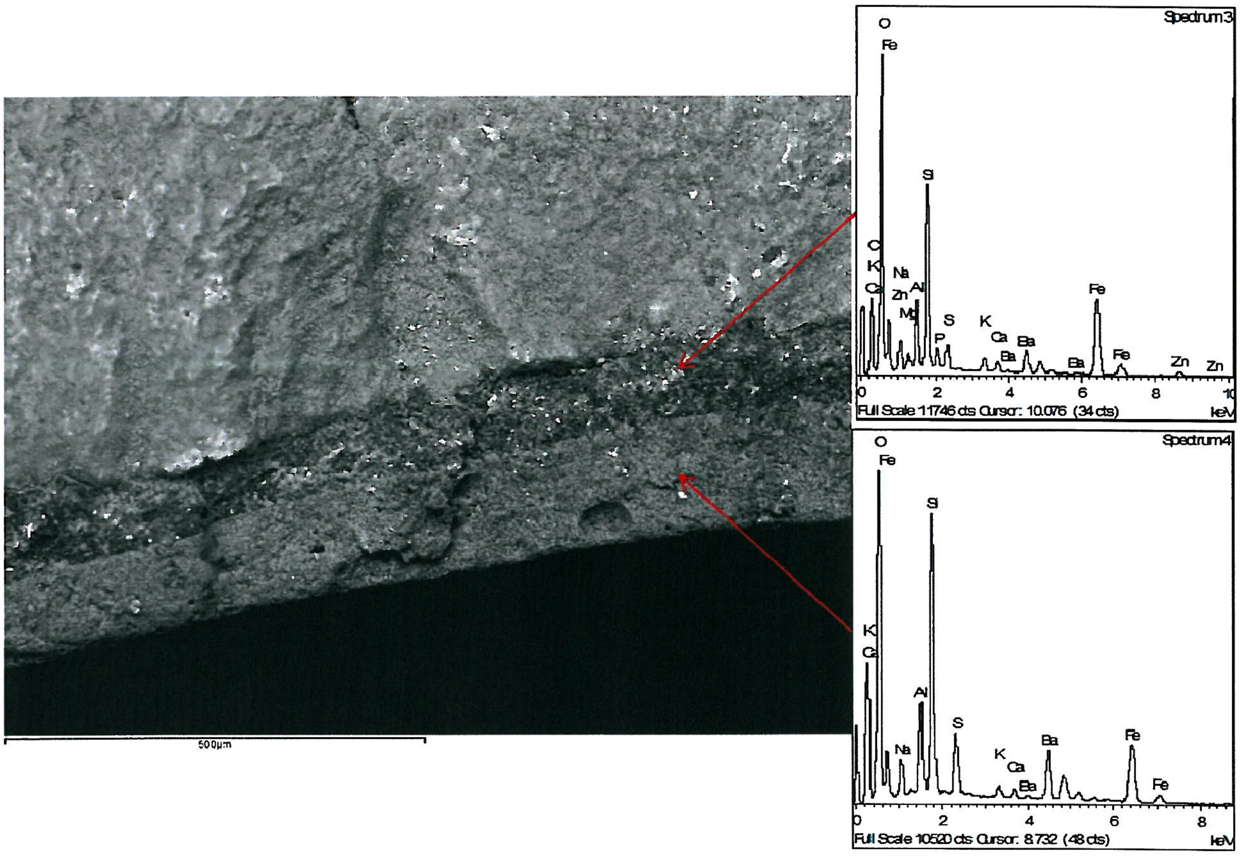

Figure 4 EDS spectrums from coating layers at the probable location for crack initiation.

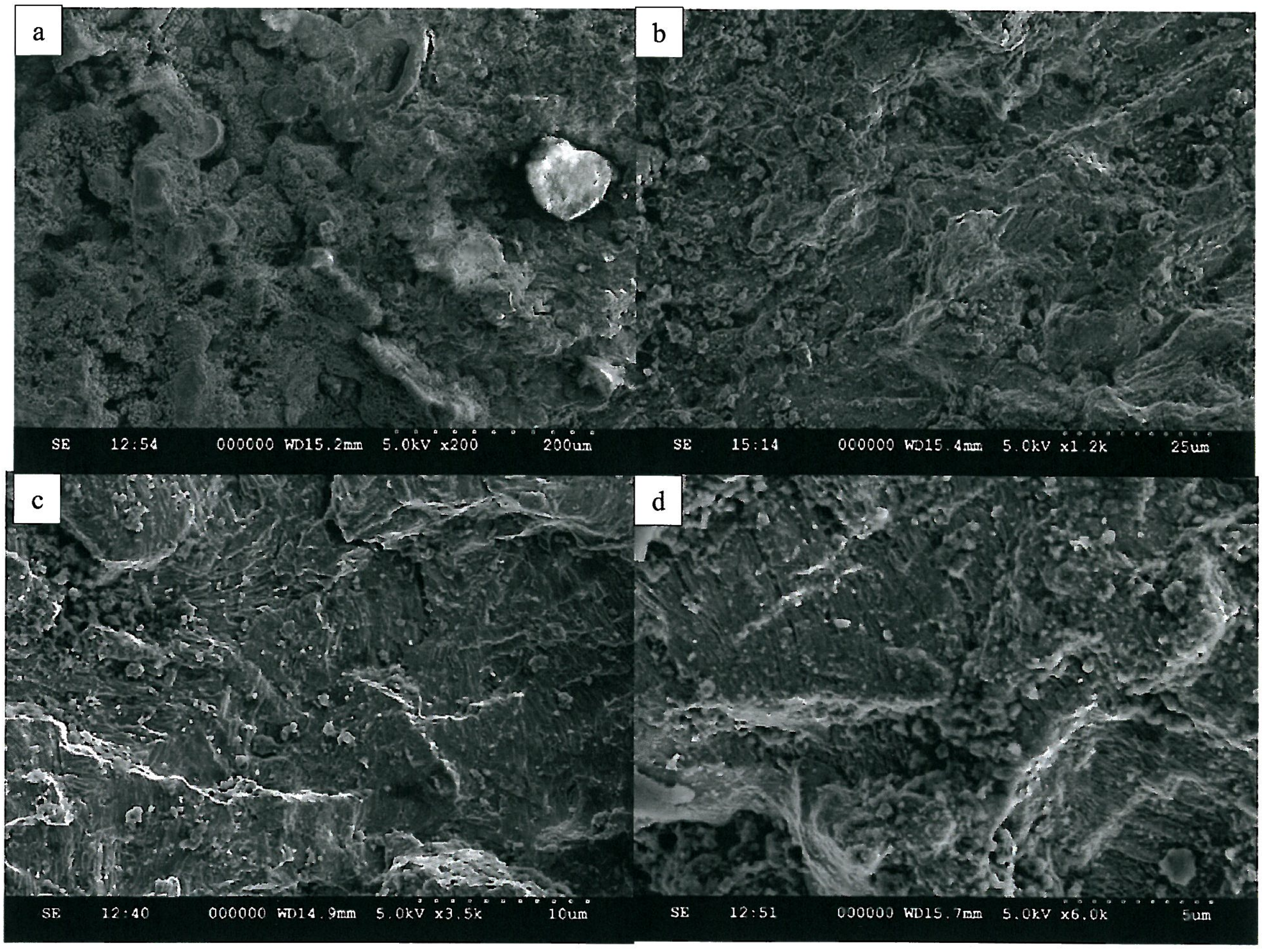

Figure 5 Characteristic pictures of torque link fracture surface observed in SEM, a-b: Corroded and contaminated surface. c-d: Images showing evidence of a striated fracture surface.

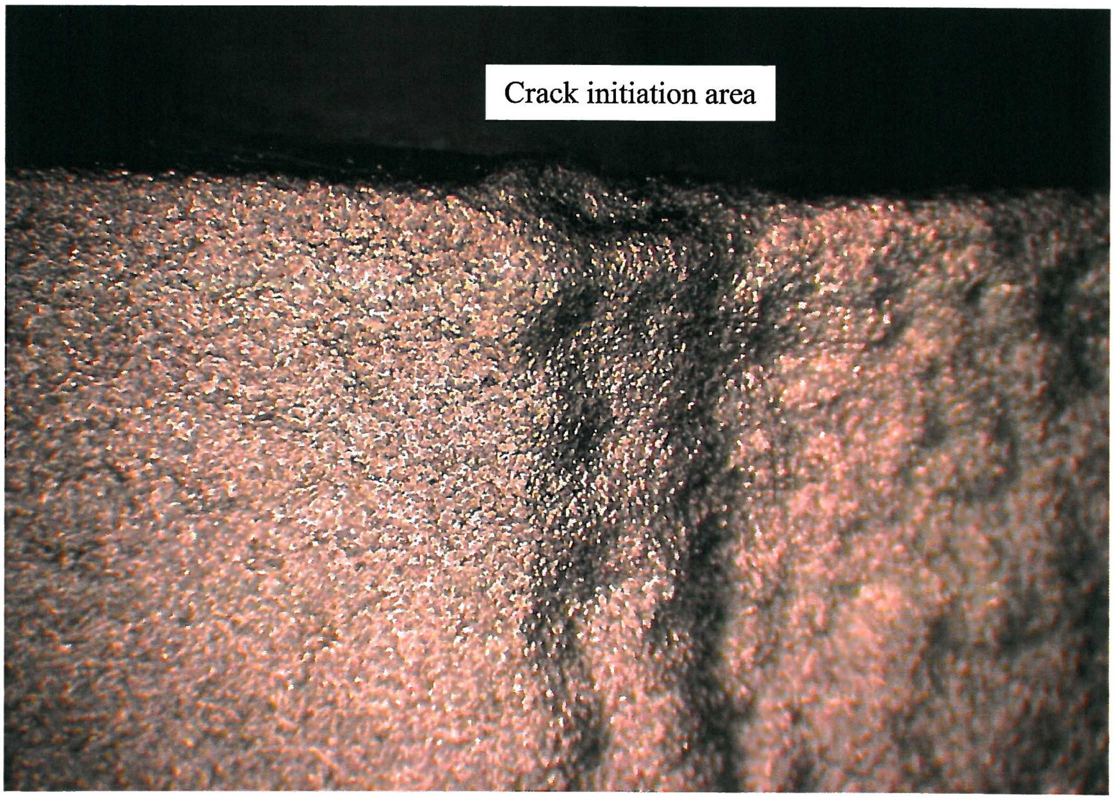

Figure 6 Image of component surface towards the crack initiation area after paint removal.

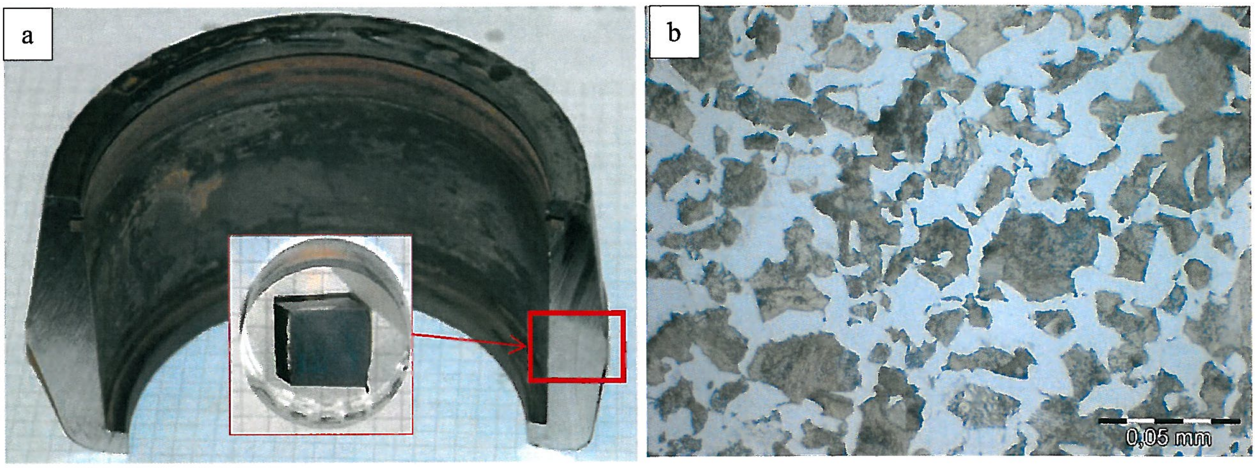

Figure 7a Overview picture of location for the metallographic sample. b: Microstructure of base material showing a ferrite, perlite structure, specimen etched in 10% Nital.

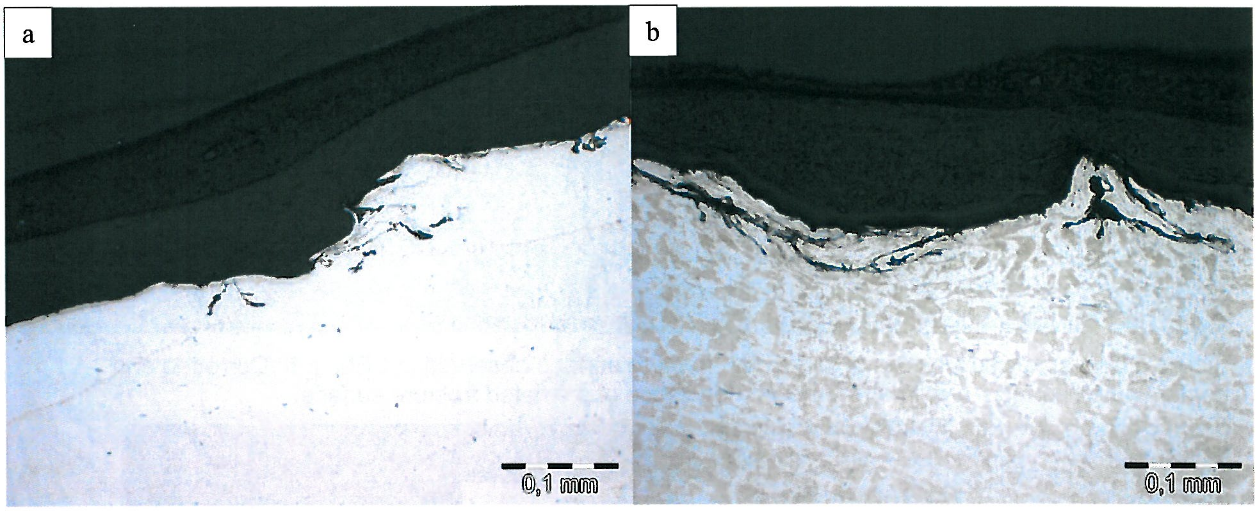

Figure 8 Picture of metallographic sample towards the surface shoving a irregular surface appearance with micro cracks associated with forging.

Table 1 Torque link base material composition, ref TI report 3420-12-003840.

C	**Si**	**Mn**	**P**	**S**	**Cr**	**Ni**
%	%	%	%	%	%	%
0.34	0.32	0.77	0.017	0.017	0.22	0.022
Mo	**Al**	**Cu**	**Co**	**Ti**	**Nb**	**V**
%	%	%	%	%	%	%
0.010	0.026	0.047	0.003	0.001	0.001	0.001
W	**B**	**Sn**	**As**	**Pb**	**N**	**Fe**
%	%	%	%	%	%	%
<0.001	<0.0001	0.007	<0.001	<0.001	0.005	98.0

2.1.2 Conclusions

Based on the obtained results it seems likely that the torque link failed due to fatigue. The fatigue crack initiation originates from surface micro cracks introduced during the forging process. There has not been possible to identify a final fracture overload region, indicating low stresses when the final fracture occurred and consequently a long period of time for the crack to develop to its full length.

The base material consists of normalized steel conforming to C35 (EN 10083-2).

2.2 Analysis of failed engine side panel

2.2.1 Results

The engine side panel fracture surface was cut from the component for further analysis. A picture of the fracture surface is shown in Figure 9 with comments from the visual examination attached. The observations are that the fracture surface consists of numerous crack arrest lines that seems to originate from the position indicated as probable crack initiation area in the picture. The actual crack initiation area is not possible to observe due to secondary damages/smearing of the surface.

A clear 2cm final fracture was also observed as indicated in Figure 9.

The visual observations were supported by fractography in SEM, Figure 10, showing contamination/corrosion of the fracture surface in the area with crack arrest lines, and a dimpled overload fracture within the final fracture area. In the transition zone between the two regions secondary cracking was observed, see Figure 10b.

A metallographic sample from the engine side panel base material was obtained to establish the base material microstructure. The structure is shown in Figure 11 and reveals a ferrite perlite structure.

The chemical composition was established using mass spectrometry, and the alloy composition is summarized in Table 2.

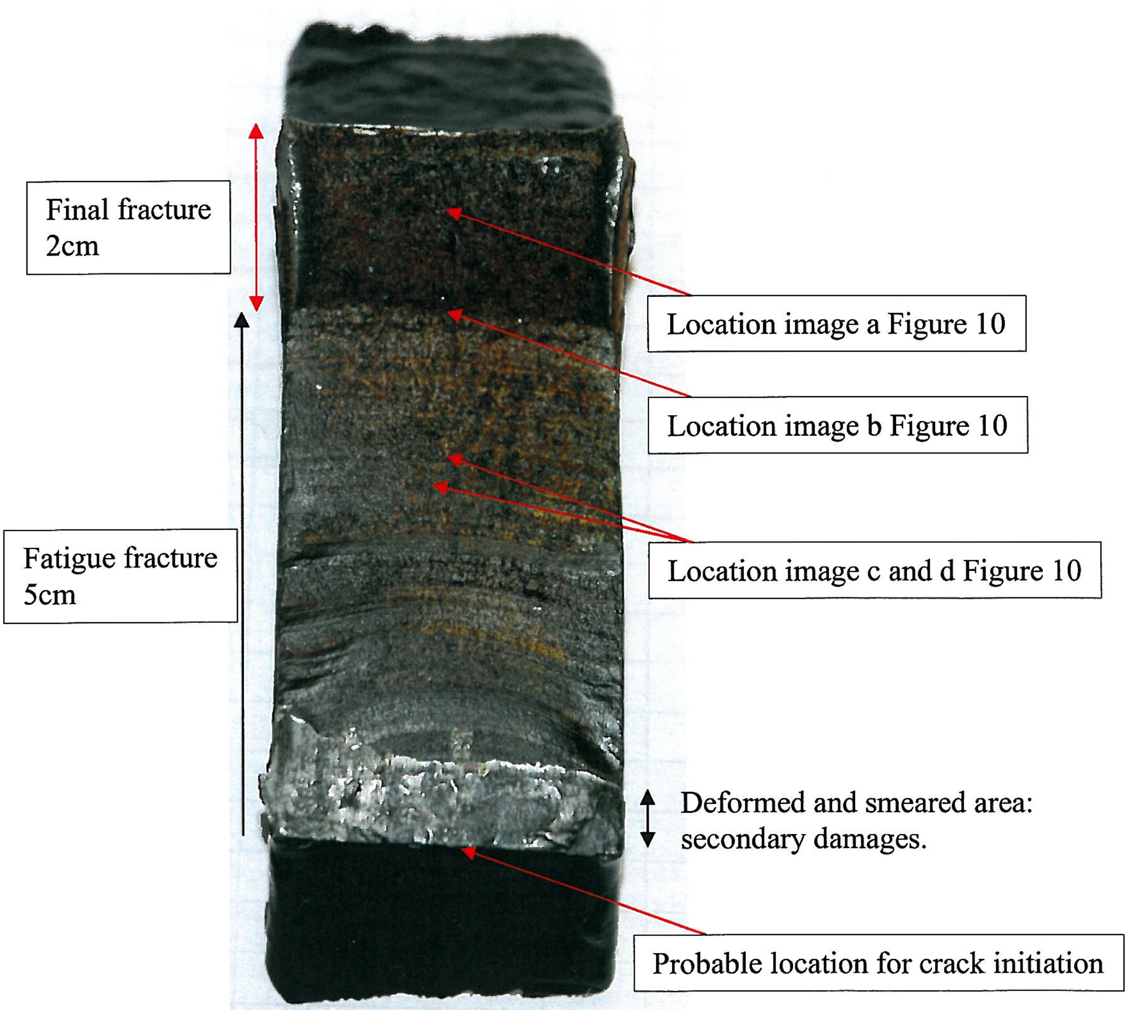

Figure 9 Overview picture of the engine side panel fracture surface including comments from the visual examination.

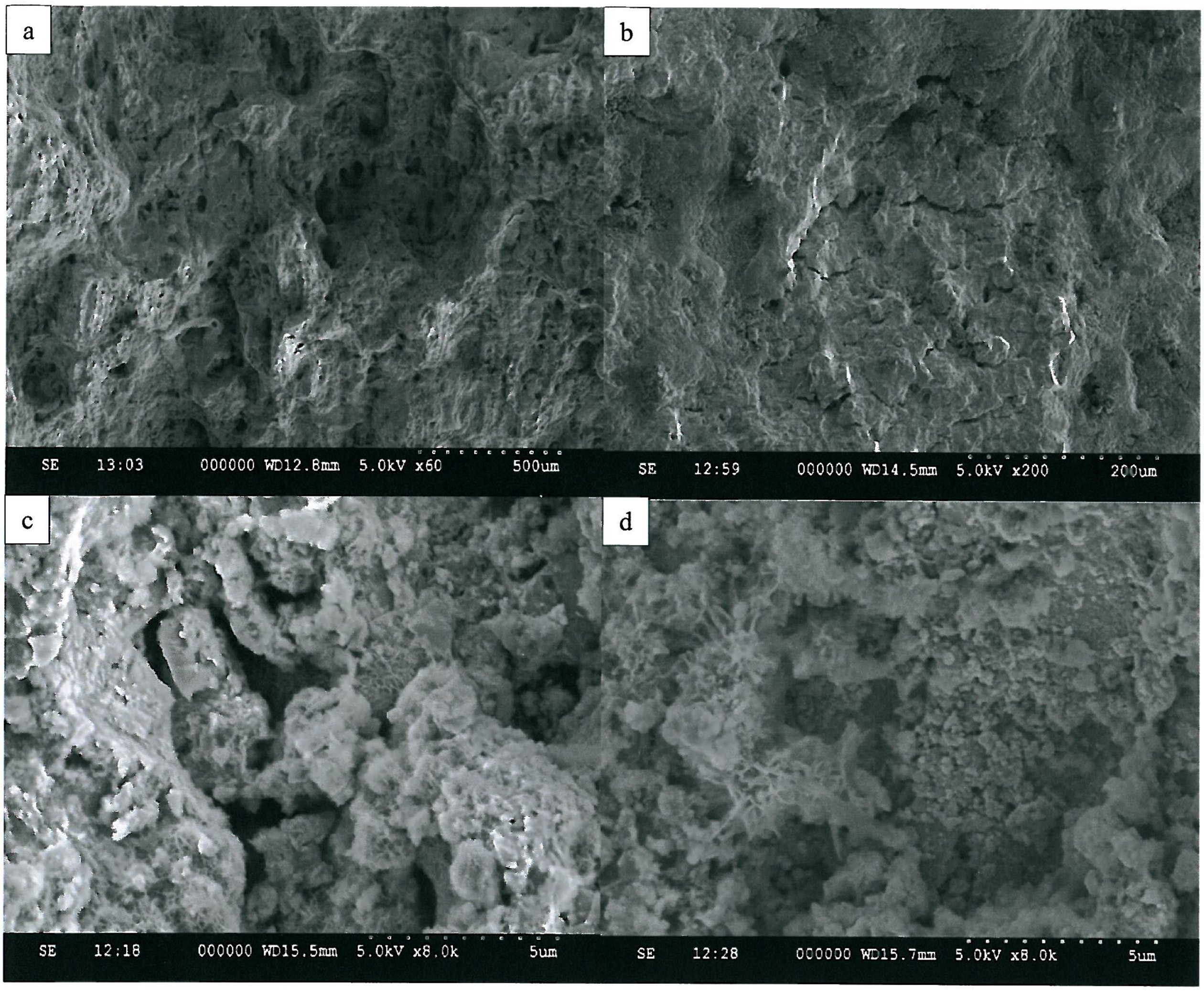

Figure 10 a: SEM image at the final fracture, showing a dimpled fracture surface. b: SEM image towards the final fracture showing micro cracks. c-d: SEM image of corroded and contaminated fracture surface.

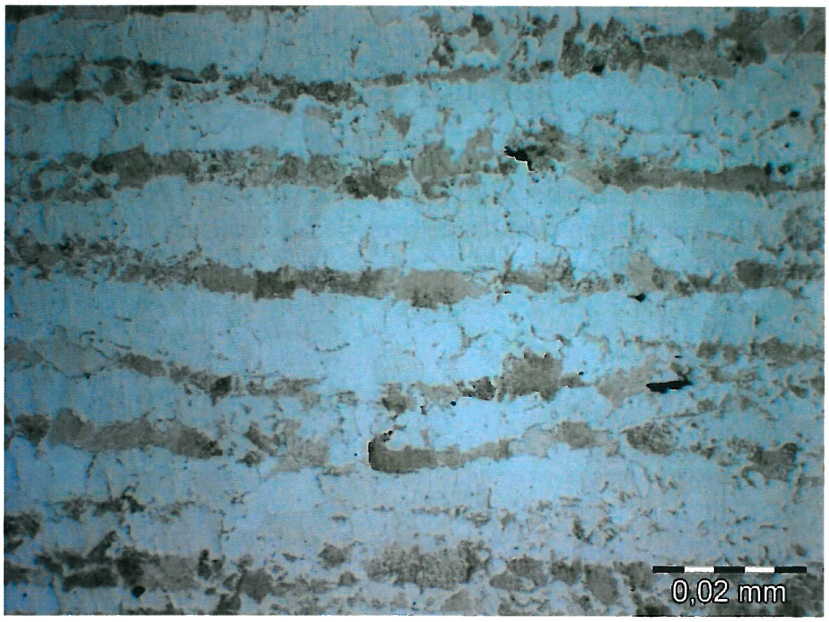

Figure 11 Picture in light microscope of material microstructure consisting of perlite and ferrite, specimen etched in 10% Nital.

Table 2 Engine side panel base material composition, ref TI report 3420-12-003840.

C	Si	Mn	P	S	Cr	Ni
%	%	%	%	%	%	%
0.16	0.39	1.53	0.016	0.010	0.029	0.028
Mo	**Al**	**Cu**	**Co**	**Ti**	**Nb**	**V**
%	%	%	%	%	%	%
0.007	0.036	0.031	0.007	0.020	0.021	<0.001
W	**B**	**Sn**	**As**	**Pb**	**N**	**Fe**
%	%	%	%	%	%	%
<0.001	<0.0001	0.007	<0.001	<0.001	0.005	97.5

2.2.2 Conclusions

The engine side panel failed due to fatigue with a final ductile overload fracture of about 30% of the total fracture area. The crack propagation rate has increased as the fatigue crack has propagated, showing evidence of low cycle fatigue towards the final fracture. Overall, the total time for the crack development must have been over some period of time.

The side panel is produced in a construction steel quality (S355 or similar).

3 Concluding remarks

The failure of the torque link does not seem to be due to under design, as the observed crack propagation in general seems to be due to high cycle fatigue. It is suggested that a study is initiated to clarify if shock loadings, such as derailment, may introduce local deformations that in turn may turn in to fatigue crack propagation. In order to improve the fatigue properties a better finish of the component surface following the forging process is possible.

The engine side panel failure was due to fatigue, initiated by overloading caused by the torque link failure.

Establishing data in order to specify the actual time for the failure to develop is outside the scope of this investigation. However, based on the fact that most of the crack propagation has occurred as high cycle fatigue, it is our view that the crack propagation could have been detected during service, if the necessary intervals and procedures had been applied.