Accident
Investigation Board
Norway

Issued November 2012

REPORT SL 2012/14

REPORT ON SERIOUS AVIATION INCIDENT AT HØNEFOSS, NORWAY 10 JUNE 2007 WITH REIMS AVIATION SA F182Q, LN-HOA

Accident Investigation Board Norway • P.O. Box 213, N-2001 Lillestrøm, Norway • Phone: + 47 63 89 63 00 • Fax: + 47 63 89 63 01
www.aibn.no • post@aibn.no

This report has been translated into English and published by the AIBN to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

The Accident Investigation Board has compiled this report for the sole purpose of improving flight safety. The object of any investigation is to identify faults or discrepancies which may endanger flight safety, whether or not these are causal factors in the accident, and to make safety recommendations. It is not the Board's task to apportion blame or liability. Use of this report for any other purpose than for flight safety should be avoided.

Photos: AIBN and Trond Isaksen/OSL

sht
Statens
Havarikommisjon
for Transport

REPORT

Accident Investigation Board Norway
P.O. Box 213
NO-2001 Lillestrøm
Telephone: 63 89 63 00
Fax: 63 89 63 01
http://www.aibn.no
E-mail: post@aibn.no

Date of issue: 02.11.2012
SL Report: 2012/14

This investigation has been of limited scope. AIBN has therefore chosen to use a simplified report format. A report format in accordance with the recommended practices in ICAO Annex 13 is only used when this is necessitated by the scope of the investigation.

All times mentioned in this report are local times (UTC + 2 hours) unless otherwise stated.

Aircraft:	
- Type and reg.:	Reims Aviation SA F182Q, LN-HOA
- Production year:	1980
- Engine/ propeller:	SMA SR-305-230 / MT Propeller MTV-9-B-S
Date and time:	Sunday 10 June 2007 at 13.50
Incident site:	Just east of the centre of Hønefoss (60° 12' 58"N 010° 19' 17"E)
Type of incident:	Serious aircraft incident, loss of propeller during flight
Type of flight:	Private
Weather conditions:	South-westerly winds, 4-5 knots. CAVOK. Temperature: 29 °C. QNH: 1,018 hPa.
Light conditions:	Daylight
Flying conditions:	VMC
Flight plan:	None
Number of occupants:	1 pilot and 3 passengers
Personal injuries:	None
Damage to aircraft:	Minor
Other damage:	Negligible
Aircraft commander:	
- Gender and age:	Woman, 52 years old
- Certificate:	PPL-A
- Aircraft flying experience:	Total aircraft flying hours: 382 hours. Past 24 hrs/ 30 days/ 90 days: 1 h 30 min./8 h 20 min./15 h. Number of landings in the past 90 days: 35
Sources of information:	Report NF 382 from the aircraft commander, report from the Defence Laboratories, Analytical Laboratory (FLO/LUFT) and AIBN's own investigation

FACTUAL INFORMATION

Course of events

The flight was a private sightseeing flight in connection with a social event. The weather was particularly good and, during the morning, LN-HOA had conducted three sightseeing flights in the course of an hour without encountering any problems. During the fourth flight, the aircraft flew at a height of 1,700 ft. On returning for landing at Eggemoen (ENEG), runway 04, the aircraft commander opted for a route just east of the built-up area at the centre of Hønefoss. This option was chosen because she did not want to subject the local community to unnecessary noise. She was also prepared to adjust the approach according to the sailplane activities that were in progress at the airport.

LN-HOA was modified with a diesel engine of the type SMA SR-305-230 and with an MT Propeller type MTV-9-B-S. During the relevant phase of the flight, the engine was set to a manifold pressure of approx. 55 inches, which, for this type of engine corresponds to economic cruising and results in a speed of approx. 110 KIAS. The engine was kept at a constant 2,200. Since the air temperature was unusually high on the day in question, the aircraft commander made frequent checks of both oil pressure and oil temperature. All indications were normal the whole time.

There were some thermal up-currents as a result of the weather. The aircraft commander has explained that she registered some minor vibrations in the aircraft as they were bypassing Hønefoss northeast of the centre. She pulled the throttle back a few millimetres, whereby the engine power would normally have been considerably reduced, but which had no effect whatsoever in this particular case. After a second or so, everything went quiet and the aircraft commander immediately implemented the procedure for restarting the engine after stoppage. The procedure involves pulling back the throttle and moving the mode handle from the normal mode to the emergency mode, so as to override the automatic adjustment of propeller pitch and fuel supply according to throttle position. Afterwards, the throttle must be pushed slowly forward so as to start the engine by windmilling the propeller. The aircraft commander observed that neither the orange warning light for “minor fault” nor the red warning light for “major fault” lit up (see fig. 2).

The engine did not start, and the aircraft commander registered that she was unable to see the propeller as expected when it moves more slowly/ ceases to turn. The aircraft commander aimed for a dead stick landing at the airport. She made a radio call on the Eggemoen frequency and said that they were approaching for landing without engine power. After a while she realised that they did not have sufficient height to reach the plateau on which the airfield is located. She therefore chose a lower-lying field approx. 1 km south of the airfield, which she knew was free of overhead cables, and turned east to reach it. The descent rate and speed was as for a standard approach: approx. 500-600 ft/min at approx. 80 KIAS. She set full flaps just before landing. The surface was dry and flat, covered in approx. 20 cm high, soft grass. The touchdown and landing roll went without problems, and the aircraft came to a halt after approx. 250 m (see fig. 1).

After landing, it was discovered that the propeller was missing. There was otherwise only minor damage to the aircraft’s engine cover.

Witnesses on the ground have stated that they heard the sound of the aircraft engine stop suddenly. Some of them had also seen the propeller disappear in the direction of a copse. The propeller was found three days later.

Figure 1: Landing site.

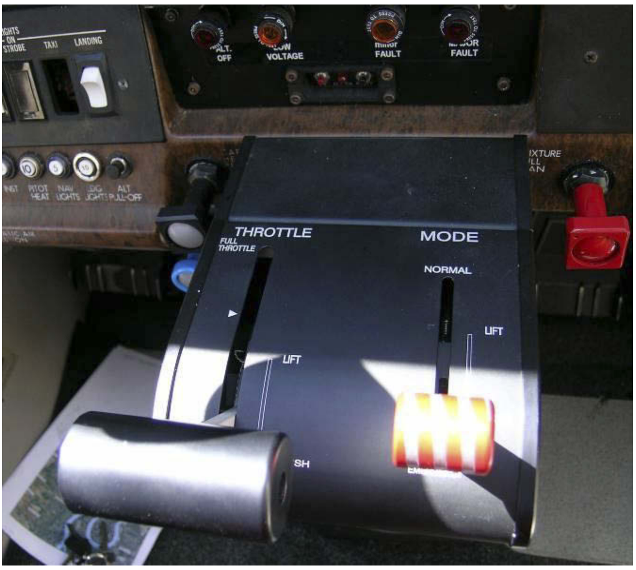

Figure 2: Throttle, mode handle and warning lights.

History of maintenance and modifications

According to the inquiries made by AIBN, the maintenance of LN-HOA seems to have been carried out in accordance with the applicable requirements. All recent maintenance, including installation of the diesel engine and propeller, was carried out by Ringerike Helikopter at Røyse/Eggemoen. At the time of the incident, LN-HOA was the only aircraft in Norway carrying this type of engine and propeller combination.

When the aircraft had flown a total of 2,294 hours and 55 minutes, it was modified with a new engine and propeller in July 2004. The original engine was replaced by a diesel engine manufactured in France, type SMA SR-305-230, S/N 1020.This engine installation has been approved for the aircraft type together with MT Propeller type MTV-9-B-S, through a French ‘supplemental type certificate’, STC no C81SF0001. The certificate was originally issued by DGAC-SFACT/N.AG in France and is therefore automatically approved by EASA. AIBN has not received all details about the approval process.

The propeller is a three-bladed wooden propeller with a glass-fibre surface coating. The propeller assembly consists of three serial-numbered blades of model 198-58B and one serial-numbered hub. The modification also included new engine mountings, adapted to the diesel engine. The work was carried out by a JAR-66-approved aircraft technician. The aircraft engineer gave AIBN a comprehensive explanation of how the job had been done. Ringerike Helikopter was the Scandinavian agent for this engine installation and was a partial owner of the engine and propeller that was installed in LN-HOA. The aircraft was used for demonstration purposes in relation to potential customers.

Due to the diesel engine being shorter than the originally installed engine, the distance between the engine block and propeller is relatively long. There are no special requirements for measuring imbalances or for restoring the balance after installation in the aircraft. Neither the workshop that installed the engine and propeller nor the owner/user carried out any form of check of balance/imbalance.

On 28 March 2007, a new fresh-from-the-factory propeller was installed on LN-HOA. The propeller was not replaced because it was damaged, but as a result of Ringerike helicopter’s business dispositions. A prioritised customer needed a propeller and took over the propeller that was installed in LN-HOA in 2004. After a while, a new propeller with hub S/N 061388 was installed in LN-HOA. At the time LN-HOA had flown a total of 2,533 hours and 55 minutes, i.e. 239 hours since the diesel engine had been installed.

This incident with loss of propeller occurred when the flying hours totalled 2,545 hours and 15 minutes. Hence, LN-HOA had been flown 11 hours and 20 minutes with the new propeller, completing a total of 31 flying cycles. Given an engine rpm of 2200 this equals approximately1500000 load cycles. Prior to this incident no imbalance during flight was recorded. The aircraft had been stored indoors and had not been subject to any unfavourable environmental exposure.

About FAA's requirements relating to the modification of diesel engine operation, in general

The Federal Aviation Administration (FAA) in USA requires the engine mounts and other engine fastening devices to be designed to withstand sudden engine stoppage as well as maximum torque multiplied by a specific factor. A flutter evaluation must be carried out in accordance with a specified procedure (14 CFR 23.629) which, among other things, requires the aircraft to be flutter-free with one cylinder inoperative. The aircraft's vibration characteristic must not deviate from the one for which the engine type is certified or for which the aircraft was originally designed – unless it can be demonstrated that the vibration pattern has no damaging effect on the aircraft structure or that the vibrations can be isolated from the structure.

Propeller installation/bolts

The propeller and hub comes as a complete unit from MT propellers, this includes factory preinstalled new bolts. The bolts are installed in the mounting flange with their heads pointing towards the propeller. The bolts consist of threaded pins that have been fitted with a nut. The nut is locked chemically (with adhesive) and with a locking pin. The bolts remain in position and are thus ready to be installed on the engine.

The bolts are designed by the propeller manufacturer and their production is outsourced to a sub-contractor. The original design is from 1998 and is designated C-060-B, and the bolt size/threads are ½" – 20UNF. The most recent revision is from 20 December 2006. Tolerance limits and materials specifications are marked on the drawing, but there is no indication of this being a critical component. The drawing does not prescribe marking the bolts with part number or otherwise. (For more information about materials, see the section: Observations and metallurgical examinations below)

The AIBN inspected the actual workshop and had interviews with those involved.The propeller is installed on the engine in accordance with SMA work card no 36 'installation of the propeller and spinner'. The bolts fitted to the propeller are inserted into the threaded holes in the engine's mounting flange and tightened to the prescribed torque (85 – 90 Nm) before they are locked in place with a locking wire (dia 0.81mm). The starting ring gear (anodized aluminium) is fitted between the two mounting flanges. Both the starting ring gear and the propeller's mounting flange fit onto the engine flange guides (see fig. 5). One guide is shorter than the five others in order to obtain correct positioning. The AIBN was told that installing the locking wire through the bolts, may require loosening the bolts and then retighten them. Both tightening and locking are demanding operations that require the use of an open-ended wrench adapter, among other things. Whether one or more bolts actually where loosened in order to fit the locking wire is unknown. Through the interviews AIBN got the impression that everybody involved understood the importance of obtaining correct torque, but it has not been possible to verify that this was the case.

Tool marks were observed on the bolt heads. The work card used for the installation was signed by both an aircraft engineer and an inspector, in accordance with the table on the job card itself as well as Norwegian regulations. There are no requirements for specifying values or the tool used (torque wrench), and this was consequently not done. AIBN inspected the workshop and spoke with those involved. The torque wrenches and other tools that were presented were calibrated and of good quality.

Figure 3: The propeller in the state it was found.

Figure 4: The propeller's mounting flange on which two of the Three remaining bolts can be seen. The locking wires are still attached to the bolt heads. Minor fretting marks can be seen on the outer diameter.

Observations and metallurgical examinations

Following the accident a search for the propeller was initiated and it was found after three days. The propeller was found with three of the bolts still attached to the propeller flange and secured by locking wires as described in the assembly instructions. The corresponding mounting flange on the engine side is supported by the crankshaft.

The crankshaft flange has six guide studs, designed to pass through the starting gear ring and into the propeller mounting flange. One of the six guide studs is shorter than the others and passes through the starting gear ring only. At the centre of each guide stud is a threaded hole for fitting the bolts attached to the propeller flange. Parts of the bolts were found in each the treaded holes. These bolts were removed and photographed, see figures 5 and 7, and figures 2 and 3 in appendix A. The bolts left in the propeller were also removed. In order to do so, the propeller was brought to AIBN's premises where the propeller hub was cut apart. Fretting is normally a result of loose connections. The contact surfaces showed some fretting, but no significant. The starting gear ring was found inside the aircraft's engine cowling. The starting gear ring is made of anodised aluminium. There was no significant fretting damage to this component either. One of the holes had a torn off edge and there was quite a deep imprint on the opposite side.

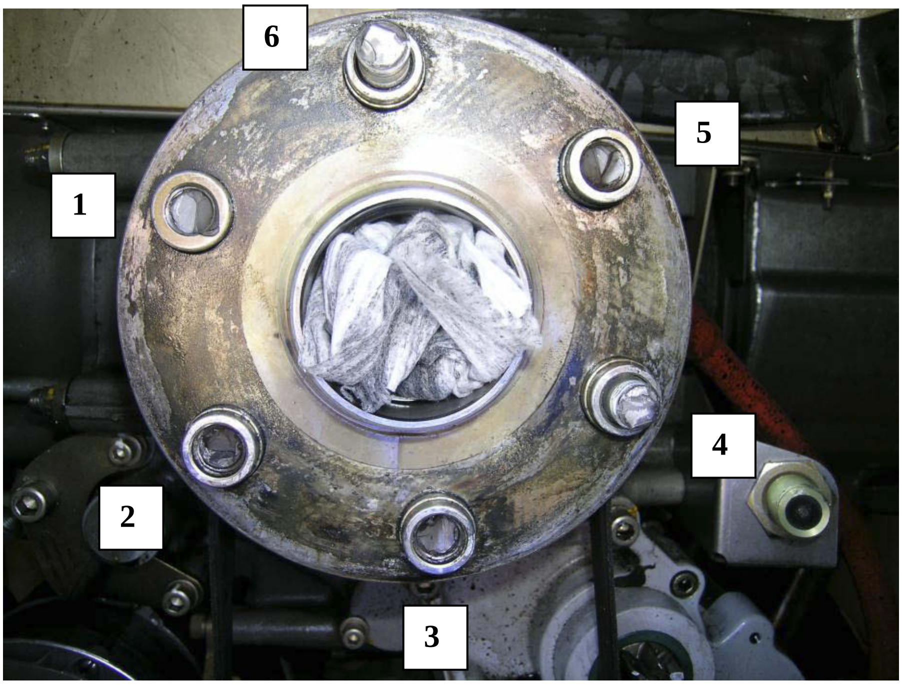

Figure 5: The flange on the engine crankshaft, showing the bolts in the state that they were observed when the aircraft had landed. The bolts were numbered as shown in the photo. Minor fretting marks can be seen on the outer diameter. Guide 1 is the shorter one.

Figure 6: Starting gear ring with fretting and imprint from tilting.

All fracture surfaces were brought to the Norwegian Defence laboratories, Analytical Laboratory FLO at Kjeller for further examination together with AIBN, see appendix A. The fracture examination was carried out using a scanning electron microscope (SEM) with energy dispersive spectrometer (EDS) and metallography equipment. The propeller manufacturer secured the procurement of reference bolts to be used in connection with the metallurgical examination.

The fracture examination showed that the bolts involved in the incident, as well as the reference bolts, had defective surface coating. The thickness of the coating varied greatly, and iron oxide (corrosion) was found to have developed between the bolt surface and the coating. Intergranular chrome particles were found towards the bolt surfaces and surface cracks were found in the area of the root of the threaded section on the bolts involved in the incident as well as on the new and unused reference bolts (see section 2.2, appendix A).

Since June 2002, the bolt manufacturer has used both the Dacromet 500A and the Geomet 500 processes to protect the bolts against corrosion. Both processes protect the bolts through applying zinc and aluminium. The surface coating must be evenly applied and have a thickness of more than 6µm. The propeller manufacturer described minimum 10µm for Geomet and 8 µm for Dacromet. Both methods have a lubricating effect that reduces the required torque. For environmental reasons, Geomet 500 has replaced Dacromet 500A which contains chrome compounds. We have not been provided with any information as to the method applied to the bolts in the aircraft or the reference bolts that we received.

No marking of the bolts was found.

Hydrogen is a by-product of the oxidisation of zinc. Hydrogen can affect and speed up stress corrosion.

The production specifications state that the bolts must be made of either SAE 8740 / AMS6322 or SAE 4340 / TE011. The latter must be protected in accordance with Geomet 500, while the former must be protected in accordance with Dracomet 500A. Both materials must have a minimum hardness of 38 HRC and a minimum tensile strength of 1,300 N/mm^2. The threads must be rolled. The bolts are designated C-060-B, where the final letter denotes the revision number.

AIBN has received a copy of a test certificate (ref. 26127/03/0506) for one of a series of bolts, dated 10 October 2006, as well as a certificate for the propeller assembly (no 20601073). The latter is not linked to the former and hence there is no traceability to the bolts in the assembly certificate we received – with the exception that the dates seem compatible. The test certificate states the material as being SAE 8740 / AMS6322 with chemical composition: C: 0.42/ Mn: 0.90/ Si: 0.29/ S: 0.017/ P: 0.015/ Cr: 0.60/ Ni: 0.44/ Mo: 0.22. Yield strength, tensile strength and elongation were in accordance with the specifications on the production drawing, but hardness was not checked /verified in the test certificate.

The fracture-mechanical examination could roughly divide the fracture into three zones, where the initiation zone (start of the fracture) seems to have been linked to stress corrosion. Secondary fracturing (branching), normally observed in connection with stress corrosion, was less extensive than expected, but the cracks that were observed can hardly be explained by any other mechanisms. The next fracture zone seems to be one of fatigue fracturing and corrosion-assisted fatigue cannot be excluded. The area exposed to fatigue mechanisms also displayed intergranular features. The final zone consisted of a very small and ductile residual fracture area.

The bolts were numbered from 1 to 6, see fig. 5. There were major similarities between the fracture surfaces of bolts 2, 4 and 6. Bolts 2 and 4 had fracture surfaces on both sides of the flange and, in bolt 6, a crack had been initiated which, if subjected to continued load exposure, would have caused the same chain of events as in bolts 2 and 4. All these bolts had broken, so that the fitted nuts (bolt heads) had come loose and were lost.

Three bolts – bolts nos 1, 3 and 5, were found in the propeller flange, see fig. 4. The remaining parts of these bolts were left in place in the propeller flange. These bolts are positioned right next to the three propeller blades, while the other three are in intermediate positions directly opposite the blades.

All the fractures were initiated at the root of the threads.

The engine cowling showed no holes from bolts that had come loose at high speed.

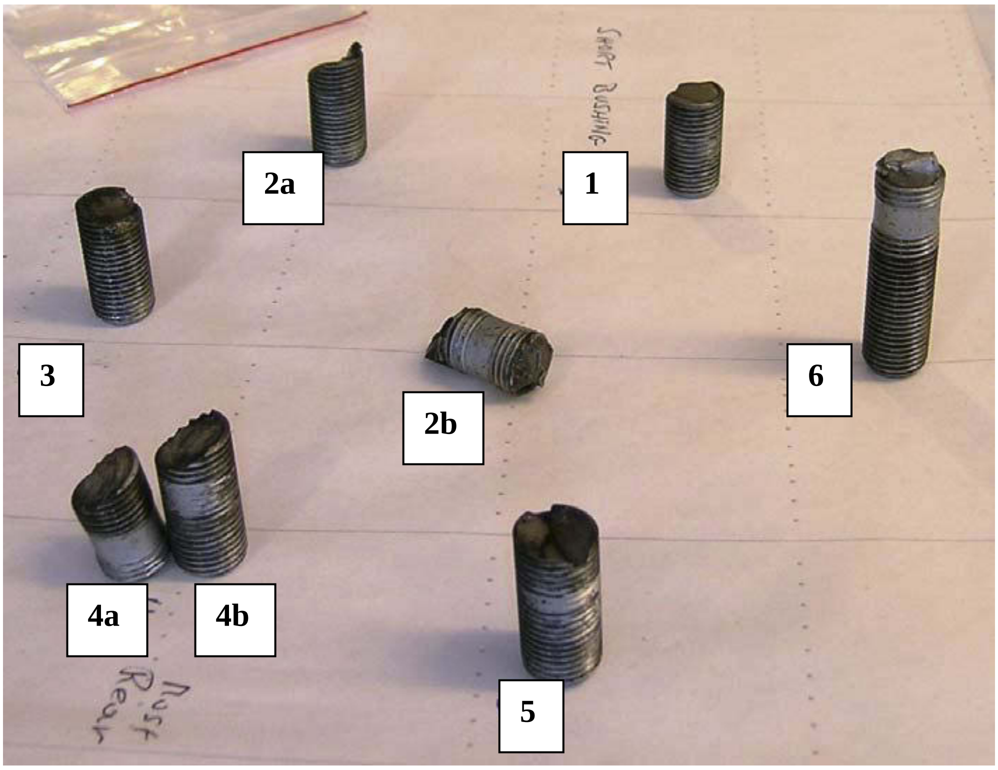

Figure 7: The bolts that were removed from the engine flange. Bolts 1, 3 and 5 have similar fracture pattern and different from 2, 4 and 6 which together have similar fracture pattern.

Metallographic examinations of the bolts from the aircraft showed an almost even hardness throughout the bolt cross-section with an average hardness of 43 HRC. The micro-structure consisted of tempered martensite (see fig.11 in appendix A). Furthermore, examination of the reference bolts showed that there were a number incidents of mechanical damage to the threaded sections (fig. 12 in appendix A). The average hardness of the reference bolts was measured to be 41HRC, and they had a tempered martensite structure, corresponding to the bolts from the aircraft. Traces of chloride were found in the EDS analysis. It was difficult to detect any structural change of the type that can normally be observed in rolled threads, and there is a great deal of evidence to support that the threads were cut and not rolled as specified by the propeller manufacturer in the production specifications. Bolts with cut threads are more prone to fatigue than those with rolled threads.

According to the propeller manufacturer, the tensile stress imposed on each bolt by the propeller is in the order of 400 kg.

No experimental work relating to fracture mechanisms, such as tensile testing or fatigue testing, has been carried out.

Dimensional control of the bolts did not show any deviations from the production specifications.

THE ACCIDENT INVESTIGATION BOARD’S ASSESSMENTS

Aircraft operation:

In the opinion of the Accident Investigation Board, the aircraft commander could not have handled the emergency situation any better. She kept calm, and it was because of her decision to land the aircraft in a large field with wide safety margins, rather than to try to extend the gliding motion across the uneven terrain along the approach to the airport, that this incident did not have any serious consequences. The fact that she had local knowledge so that she knew where there were high-voltage power lines helped to secure an optimum landing site. Since the propeller fell off and there was a danger that it would hit people on the ground, it was favourable that she chose a route that did not pass over built-up areas. AIBN do not think that the way in which the aircraft was operated can explain the loss of the propeller.

The modification:

The engine and propeller are approved as one unit for the type of aircraft in question. AIBN has found no evidence for claiming that the loss of the propeller can be ascribed to the nature or workings of the diesel engine, but there may be reason to examine more closely the certification, verification and testing of the engine and propeller as a single system. One of the reasons for why this should be done is that the all six bolts broke approximately simultaneously and bolts next to the propeller blades (bolts 1, 3 and 5) display a different fracture pattern from the bolts in the intermediate positions. Another factor to consider is the relatively great distance from the engine block to the propeller together with the nature of the diesel engine with its rougher behaviour than the traditional engines. This design imposes a major requirement for vibration damping and balancing in order to, together with other things, to avoid resonance. The engine mountings were visually inspected, and found to be free from cracks and appeared to be in accordance with the specifications, but no exact measurements were taken.

Propeller installation:

The installation is narrow and sub-optimal in order to obtain required torque. The possible need for loosening torque when fitting the locking wire, is also an unlucky result from this narrow installation. Tool marks on the bolt heads indicates that a tool was used, and possibly with the intention to achieve the correct torque. Neither the installation procedure, nor the regulation does require the applied torque to be written down and thus this was not done. AIBN believes that traceability is always an advantage, and that such values should therefore be noted. The completion of the installation was signed for by a JAR-66-approved engineer and an inspector. The individual items had not been specifically signed for, only the three individual pages of the procedure. AIBN has found this to be common practice, particularly in the GA community. AIBN regards this practice as unfortunate in that it increases the chance that an item will be forgotten or inadequately executed. AIBN report 68/2000 includes two recommendations for the Civil Aviation Authority Norway concerning a similar theme[1].

The surface coating has a lubricating effect, and this means that there are reasons for assuming that any defects in the coating and in the threads would change the measured values in relation to those prescribed by the manufacturer. AIBN has not tested this. Nor has AIBN conducted any abrasive tests and it is therefore unable to give an opinion as to degree of movement necessary to obtain the minor fretting marks. Fretting is a result from movement and thus most possibly from insufficient torque during installation.

---

[1] These recommendations refer to BSL B3-2, now replaced by BSL B2-4 section 12. BSL B2-4 section 12 stipulates overall requirements for documentation and does not require values to be written down or the tools used to be documented. This means that AIBN’s recommendations have not been implemented.

AIBN is of the opinion that insufficient torque can lead to increased vibrations and thereby resonance which can contribute to a rapid crack growth leading to all six bolts breaking simultaneously.

The material quality/geometry of the bolts:
Although the propeller manufacturer has been contacted on several occasions, it has not presented any description of the process for surface treatment of the bolts, except in the form of advertising material. Hence it is difficult to say whether or not a description of the complete fabrication process exists, and how the process that was carried out might have deviated from the prescribed one that may or may not exist. Surface corrosion before application of corrosion-protection coating, as well as notches and damage to the threads is a sign of defective handling of materials and process control.

What seems quite clear, however, is that the process carried out does not ensure the desired quality. Due to inadequate documentation, the chrome-rich area towards the surface of the bolts cannot be explained either. If the process includes chromic acid cleaning, this might affect the fracturing process as observed in this case – see the next section. Chromium enrichment could also be caused by non-conforming heat treatment of the bolts. Iron oxide/corrosion on the surface will adversely affect fracture growth in that it will both initiate and speed up fracture growth. An uneven coat thickness in areas where there is little or loose surface protection results in local corrosion and can also initiate and speed up fracture growth in the way that was observed.

Micro-cracks in the surface, as observed on the new and unused reference bolts, are fracture initiation points. Whether the micro-cracks should be ascribed to heat treatment, early stress corrosion or the surface protection remains unknown. Whatever the origin, AIBN deems this to be quality non-conformity and not something one would expect in a critical component designed for use in an aircraft.

The production specifications require the threads to be rolled. AIBN has no evidence that this was done. There are no signs of any cold-worked structure of the type that might be expected in the case of cold-worked materials such as rolled threads. If the threads are cut, this reduces their fatigue fracture resistance. Furthermore, the threads of the reference bolts were found to have suffered major impact damage, which would also reduce their fracture resistance. Whether or not the installed bolts had the same defects as the reference bolts, has not been proved.

Fracture initiation was in the root of a threaded section in each case. All the quality non-conformities described above would tend to contribute to a fracture that would be likely to start in this area.

Material quality and hardness was in accordance with the requirements of the propeller manufacturer's specifications.

The proven quality results in a final product that deviates from the prescribed one and which is not in accordance with what one would expect of bolts in the aviation industry. Even if the proven bolt quality solely cannot explain the fractures, it will have contributed to initiation and maybe to the rapid fracture growth.

The production drawing is not marked so as to reflect that the bolts are critical components. A Part 21 organisation, such as the propeller and engine manufacturer, is usually required to have processes for handling critical components and the production drawings are also required to be marked with ’critical part’ as appropriate. The background to such marking is that it should trigger particular care during production, further handling and documentation.

There appears to be inadequate traceability relating to the bolts on the part of the propeller manufacturer. AIBN has not obtained any unambiguous documentation of what batch the bolts in question belonged to, and hence of where the remaining bolts from the same batch might be today. AIBN has been informed that the propeller manufacturer immediately after this accident started his work on improving the production quality of the bolts. To which extend these improvements meet the findings from this investigation is unknown. The propeller manufacturer states that by August 2012 there are 40 aircraft with this combination of propeller and engine worldwide and LN-HOA is the only one having lost its propeller.

Fracture mechanism:
All the bolts had broken and it was therefore impossible for AIBN to determine what torque had been applied. Some fretting is observed and thus it can be concluded that there has been a degree of movement.

The fracture started as an intergranular fracture, with stress corrosion as the main mechanism. It than went on to become a fracture in which fatigue was the main mechanism, but it was still of an intergranular nature. Corrosion-assisted fatigue cannot be excluded. The residual fracture was ductile and caused by overloading after the cross-section had been reduced to a point where it could no longer withstand the tensile forces working on the bolt. The fact that the residual fracture is small is a confirmation that the force created by the pull of the propeller was very small. All the proven defects relating to the fabrication of the bolts contributed to speeding up fracture initiation and fracture growth. AIBN is unable to fully explain why all six bolts broke at approximately the same time after only 11 hours and 20 minutes of service. Neither why there are two groups of similar fracture surfaces, each group different to the other. This can be related to loosening of every second bolt during locking with lock wire. Or, it can be due to its individual position near or between the propeller blades. A loose connection and resonance following vibration/imbalance during all or parts of the 1 500 000 load cycles can explain the rapid fatigue crack growth and simultaneously fracture of all six bolts. Stress corrosion and possible corrosion-assisted fatigue is related to a less than perfect production quality.

An increase in the torque would increase the tensile forces working on the bolts and hence speed up the process of stress corrosion. This is however less possible in this case.

The aircraft was not stored in a corrosive environment or exposed to other external corrosive loads that might explain the rapid fracture growth. The small amounts of chlorine that were found could just as well come from tap water used for cleaning or from the test preparation in the laboratory.

The AIBN believes that a degree of movement in the propeller and engine mount together with the load cycles from the running engine and propeller may have created resonance leading to the rapid fracture. The imperfect quality of the bolts initiated cracks which most probably where present at time of installation. Wether these fractures would have happened with flawless bolts is not considered.

Summary/ conclusion:

1. The Aircraft lost its propeller after all six mounting bolts fractured after only 11:20 flight hours

2. The operation of the aircraft did not contribute to the loss of the propeller.

3. The way the aircraft was handled before and during the incident contributed to the favourable outcome whereby nobody was injured.

4. The fracture started as a stress corrosion fracture and continued as fatigue fracturing, and corrosion-assisted fatigue cannot be excluded.

5. Quality assurance in connection with the fabrication of the bolts was poor.

    - The threads appear to have been cut rather than rolled.
    - All the fractures where initiated at the root of the threads.
    - Bolts where corroded before corrosion-protection was applied. There was also potential for external damage to the bolts during fabrication.
    - Corrosion speeds up stress corrosion and corrosion-assisted fatigue failure. These fracture mechanisms develop very quickly.
    - Whether or not the chrome-rich areas and surface micro-cracks can be explained by non-conforming heat treatment is uncertain.

6. The material quality appears to have been in accordance with the specified requirements.

7. There was inadequate traceability.
    - The manufacturer has not submitted any documentation of traceability in the production of bolts.
    - There was inadequate traceability in connection with the installation of the propeller in that the various steps in the process had not been signed for individually with indication of torque values. There is no documentation of which torque wrench was used or of whether it was calibrated or not. This indicates that the safety issues described in the HSL report SL 68/2000 have not been properly addressed.

8. It has not been proven that the correct torque was applied when mounting the propeller. Slight fretting of the contact surfaces does indicate too low torque.

9. The fact that the fracture did not start as a fatigue crack and only slight fretting indicates that other mechanism are dominating.

10. AIBN believe that reduced mounting torque could have led to a degree of movement and created vibrations and thereby resonance which has dominated the rapid fatigue fracture growth and led to all six bolts fracturing simultaneously.

11. AIBN has not conducted tensile testing, fatigue testing or abrasive testing. Such tests might have provided more information as to how much movement that is necessary in order to create the observed fretting and thereby the applied torque. Tensile testing and fatigue testing might also have verified the material quality and the effect on the rapid fracture growth of the surface defects that were observed.

12. AIBN has found no evidence for claiming that the loss of the propeller can be ascribed to the nature or workings of the diesel engine, but the relatively long distance between the engine block and propeller imposes strict requirements for damping of vibrations and balancing in order to avoid resonance. It is thus is of major importance to regard the engine and propeller as a whole during testing, verification and certification.

Accident Investigation Board Norway
Lillestrøm, 2 November 2012

Annex A: Report 071109.01;”Failure investigation of bolt cracking resulting in propeller loss, Cessna 102Q” Defence laboratories, Analytical Laboratory FLO, Kjeller Norway.

NDLO / ADK

Defence Laboratories
Analytical Laboratory
Chemistry and Materials Technology

Client **Accident Investigation Board Norway** **Att. Kåre Halvorsen** P.O.Box 213, NO-2001 Lillestrøm, Norway	**Technical Report**
Copy	Client's ref

Title

Failure investigation of bolt cracking resulting in propeller loss, Cessna 182Q

Report No 071109.01	Date of receipt of commission 2007-06-12	Date of publication 2007-12-17
Job No / Sample No M-07-259	Number of pages 18	Number of appendix -
Work carried out by Øyvind Frigaard		Head of Analytical Laboratory Tor A Gustavsen

Summary

The Norwegian Defence Laboratories was asked to assist in the analysis of bolt fractures that had resulted in propeller loss for a Cessna 182Q during flight.

The client wanted an evaluation of possible causes for the observed failure. The investigation involved fractography in SEM, equipped with EDS, and metallography.

The investigation has shown that the bolt quality is in general questionable as both the failed bolts and the received reference bolts shows irregularities as uneven coating distribution, oxides at the coating/bolt interface, intergranular chromium particles towards the bolt surface and crack initiations. The true cause for the observed deviations must be established. Quality and process control procedures should be revised.

The later parts of the bolt crack propagations are due to fatigue. The final fracture, when observed is very small and indicates low loading at the time of the final fracture. In order to explain the intergranular fracture surfaces observed at the crack initiation areas a fracture mode including stress corrosion cracking and corrosion assisted fatigue can not be excluded. Although the amount of branching that would be expected in the case of stress corrosion cracking is questionable, other explanations for the observed secondary cracking has not been established. The intergranular features observed along with the fatigue crack propagation could be related to high stress amplitudes. However, the very small ductile final fractures observed, does not support this mode, and corrosion assisted fatigue seems to give a more sound explanation. Corrosion assisted fatigue would increase the cack propagation speed thus resulting in development of a critical failure over a short period of time as observed in the given case. In order to obtain the true mode for the observed failure experimental work including corrosion, strain and fatigue testing must be performed. Such testing has not been in the scope of the current investigation.

1 Introduction

The Norwegian Defence Laboratories was asked to assist in the analysis of bolt fractures that had resulted in propeller loss for a Cessna 182Q during flight.

The client wanted an evaluation of possible causes for the observed failure. The investigation involved fractography in SEM, equipped with EDS, and metallography.

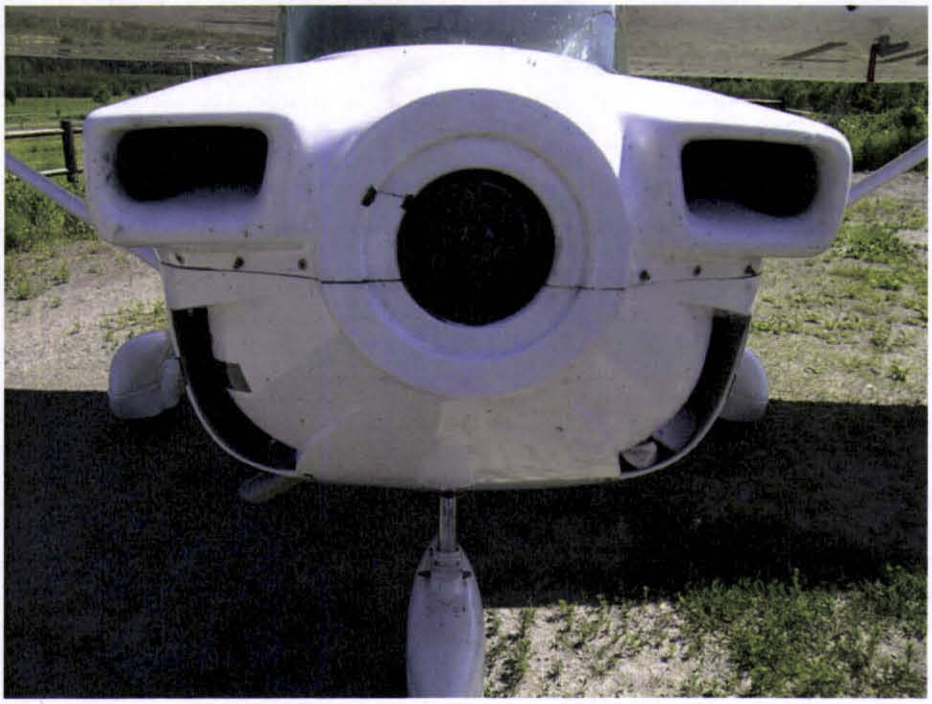

Figure 1 Picture of Cessna 182Q with propeller loss, picture obtained from AIBN.

2 Results

A picture of the fractured bolts as observed on the airplane is shown in Figure 2. The bolts are numbered for identification through the investigation. An overview picture of the bolts is shown in Figure 3. Bolts 2 and 4 showed two fractures and are identified as 2*ab* and 4 *ab* respectively. Three bolts were later found on the propeller, and these bolts are shown in Figure 4. Bolts 2 and 4 had fractured at two different locations. An additional crack was later observed on bolt 6, the crack was forced opened in the laboratory and the fracture surfaces added to the investigation.

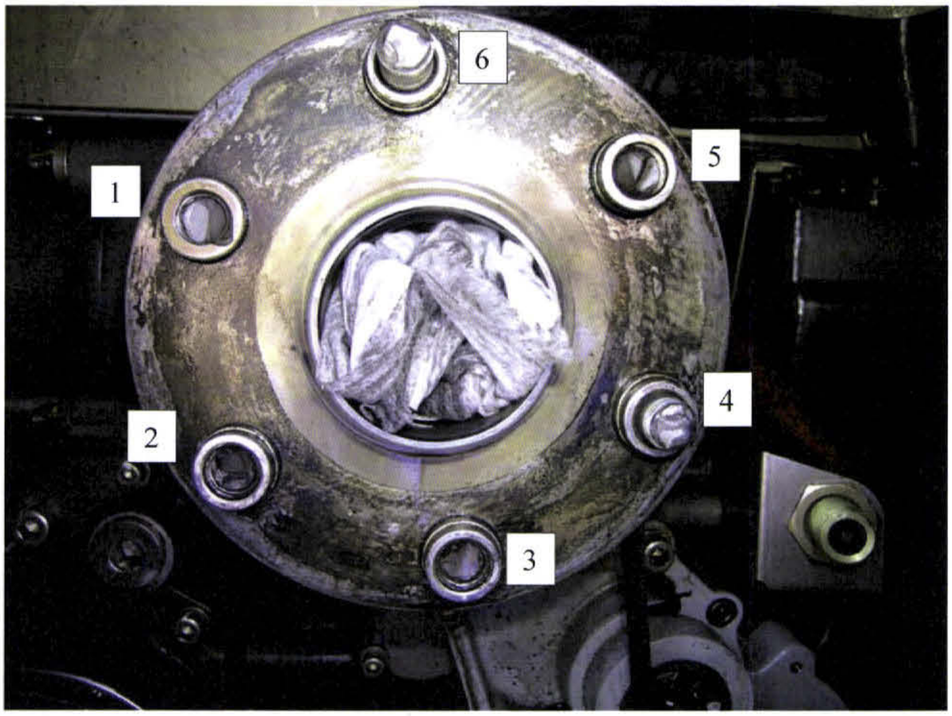

Figure 2 Picture of fractured bolts still mounted on the aircraft. Picture from AIBN.

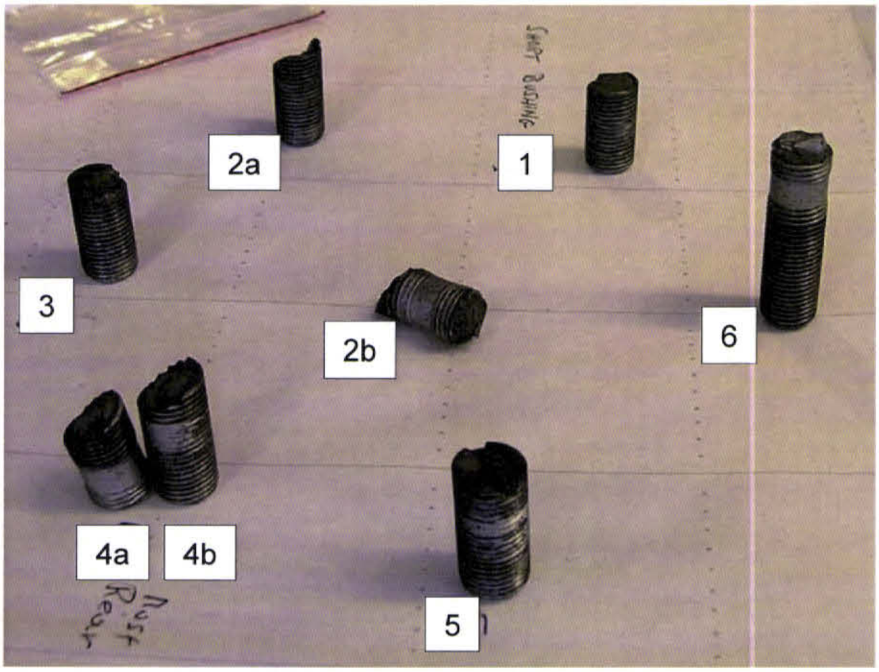

Figure 3 Overview picture of bolts after dismounting.

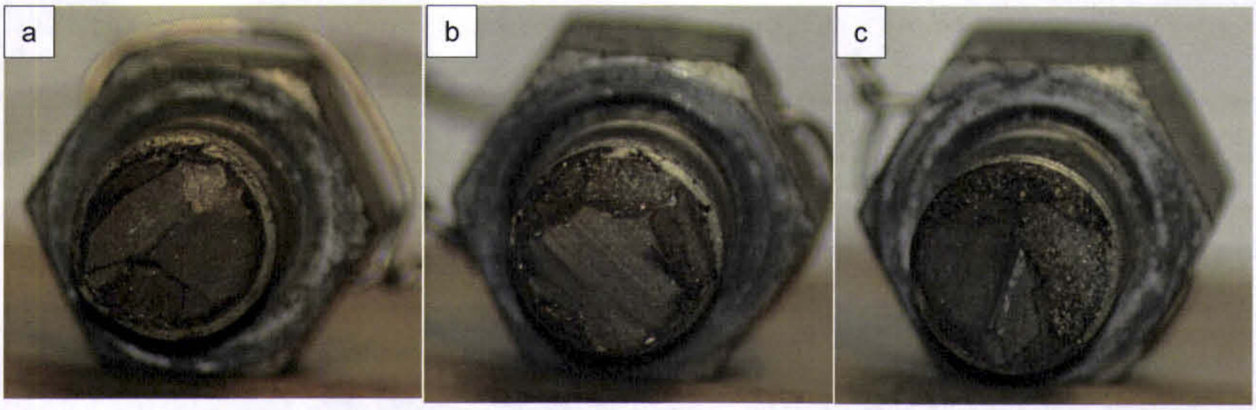

Figure 4 Picture of fractured bolts dismounted from propeller. a: Bolt 1, b: Bolt 3, c: colt 5, see Figure 2 and 3.

2.1 Fractography

The fracture surfaces were characterised using SEM in order to reveal mechanisms for the crack propagation. In general the fracture surfaces show a mixture of intergranular and fatigue crack propagation. Several cracks seem to have initiated from areas showing a brittle intergranualar fracture surface. As the crack has developed, characteristics typical for fatigue is readily observed. The final fracture when observed is very small and ductile indicating low loading at the time of the final fracture. Characteristic pictures of the fracture surface for bolt 6 are shown in Figure 5, pictures obtained from all six bolts are shown in Appendix 1.

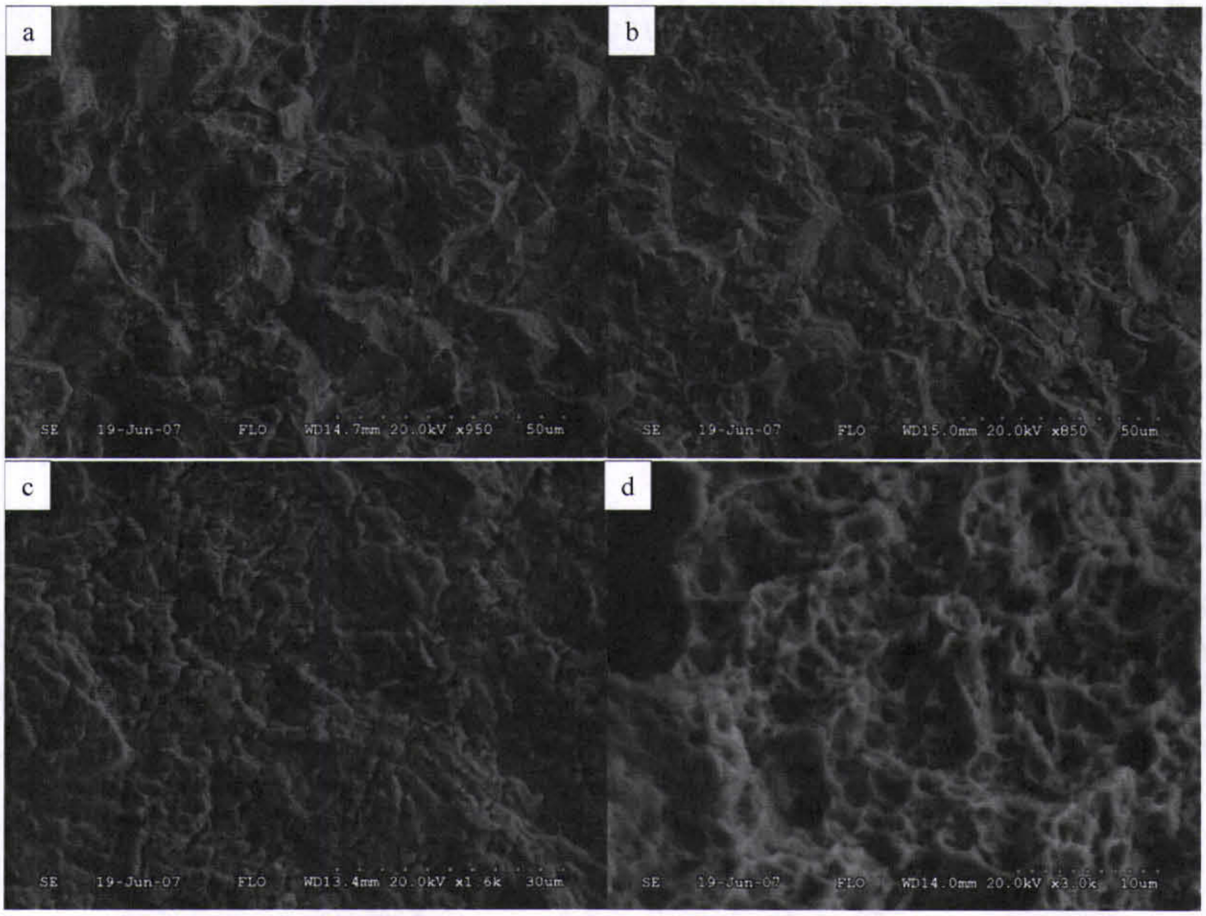

Figure 5 Representative picture of fracture surface as observed in SEM for bolt 6.

2.2 Metallography on fractured bolts

A cross section was made through bolt 4a, see Figure 3, the specimen where mounted and processed for metallographic examination including SEM equipped with EDS. Figure 6 show a picture of the cross section through one of the thread roots. The picture and the attached EDS spectrums show that the bolt has been coated with a zinc based corrosion protective layer, the bolt surface is however covered with a iron oxide layer, further chromium rich particles are readily observed along the grains at the base material towards the surface. The picture also identifies what appears to be a small crack. Figure 7 show a picture at lower magnification of the same area shown in Figure 6, the picture show two additional possible crack initiations and an uneven distribution of the zinc based coating. Figure 8 show two pictures of the cross section through fracture surface of bolt 4a in Figure 3. The pictures show a rough intergranular surface appearance with indications of small secondary cracks. Further the images and EDS spectrums in Figure 9a-c show traces of corrosion products and micro cracks within the cross section of the fracture surface. The hardness profile shown in Figure 10 did not reveal any major variations in the hardness through the cross section of the bolt. The microstructure of the bolt base material is shown in Figure 11 and consists of tempered martensite. The bulk hardness was measured to be 43 HRC.

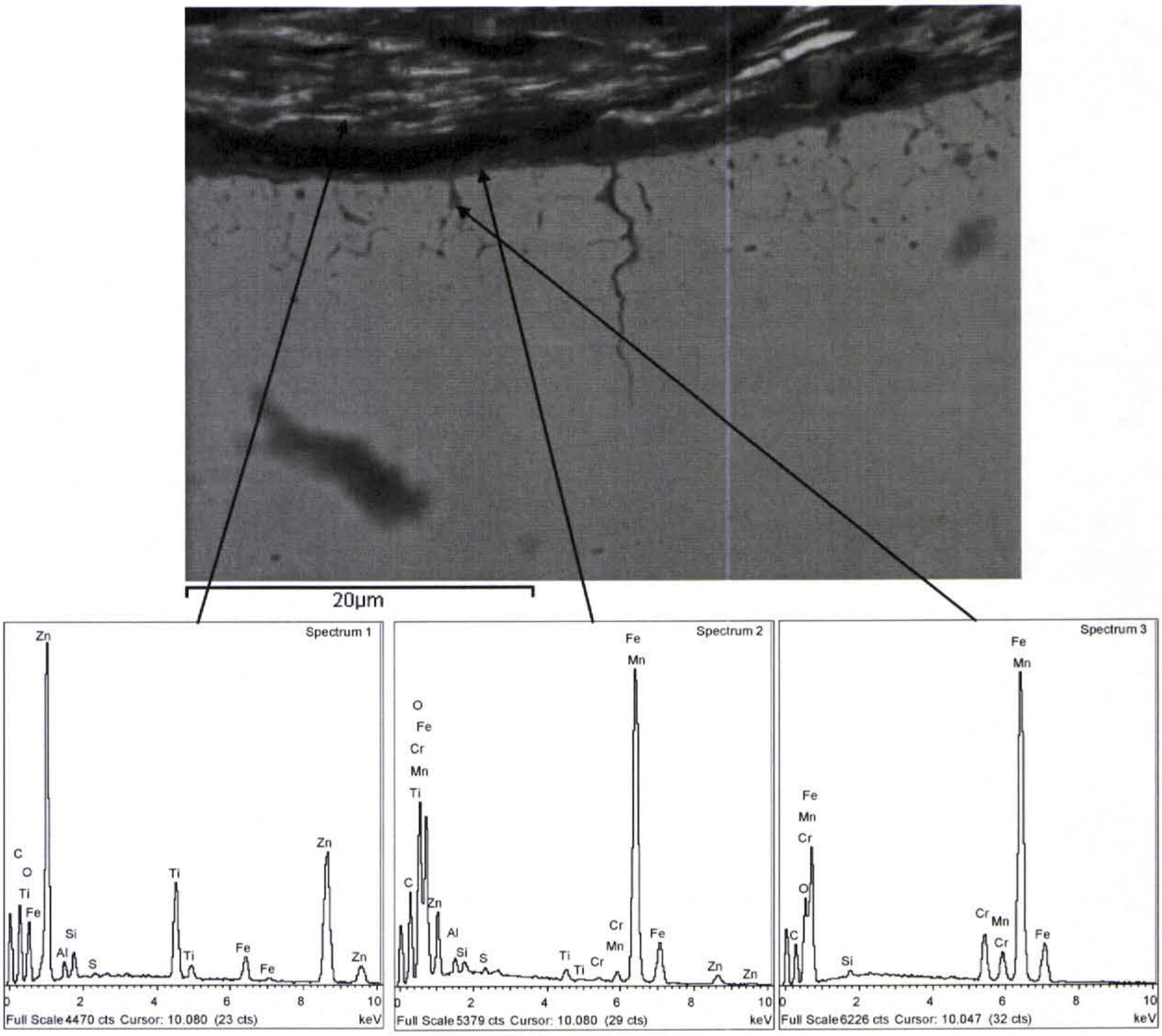

Figure 6 Picture of cross section though fractured bolt number 4a in Figure 3. The attached EDS spectrums show: Spectrum 1 Zinc based corrosion protective coating. Spectrum 2 Oxides at the coating/base material interface. Spectrum 3 Chromium rich particles along grain boundaries.

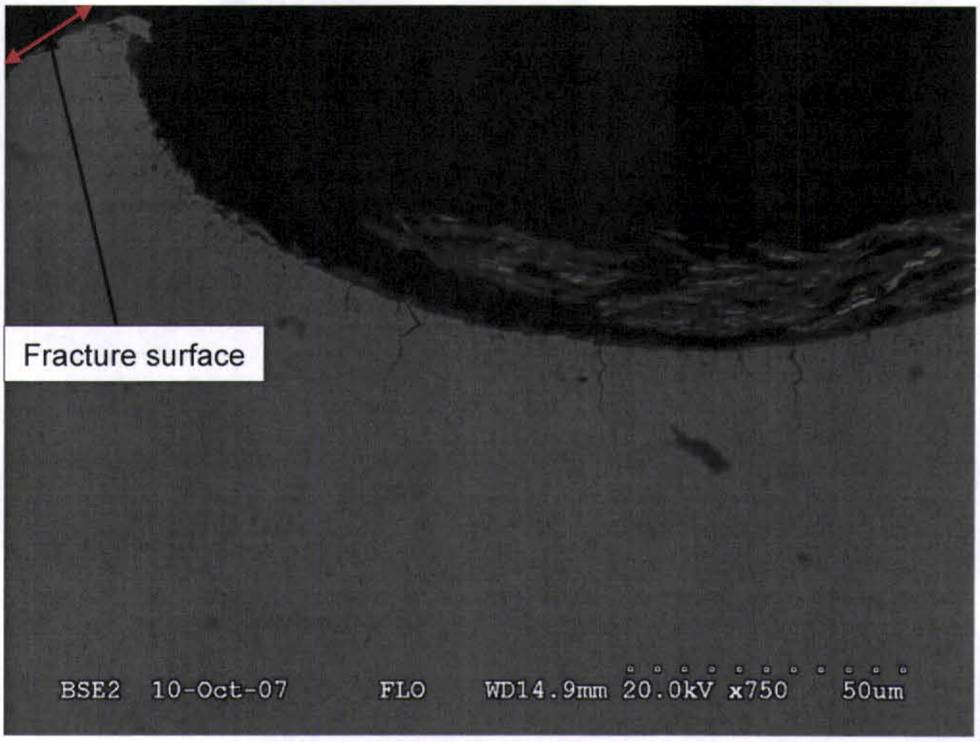

Figure 7 Picture of cross section through thread root close to the bolt fracture. Area also shown in Figure 6.

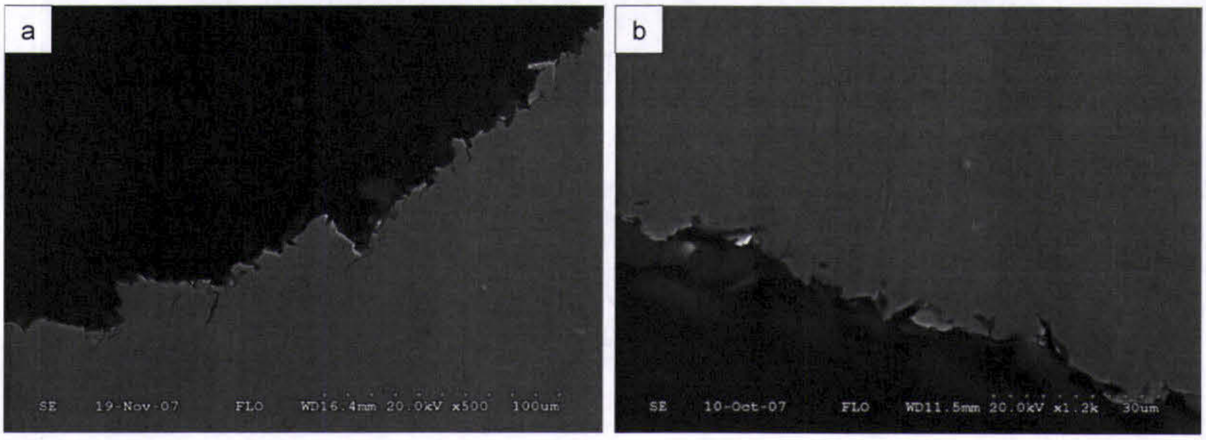

Figure 8ab Picture of cross section through fracture surface 4a in Figure 3.

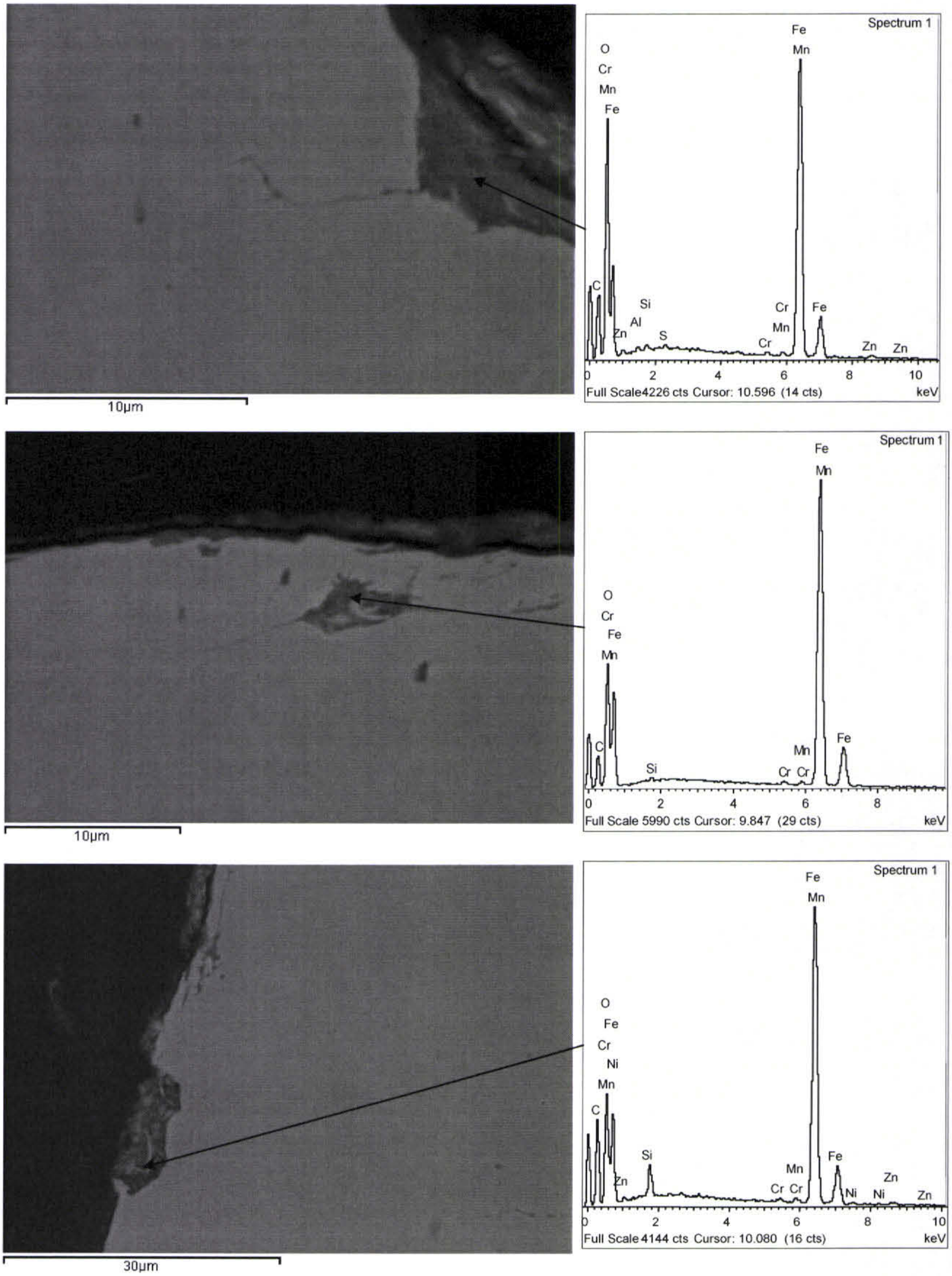

Figure 9 a-c Picture from the cross section of fracture surface 4a in Figure 3 with EDS spectrums showing traces of iron oxides.

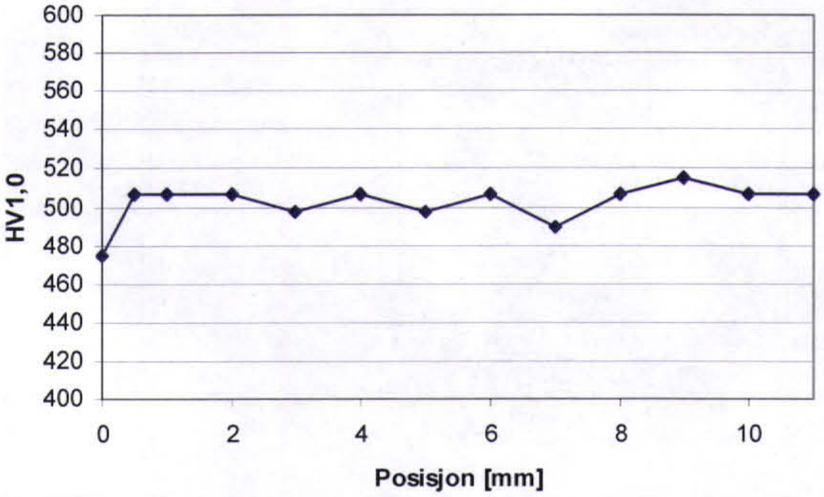

Figure 10 Hardness profile through the cross section of bolt 4a in Figure 3.

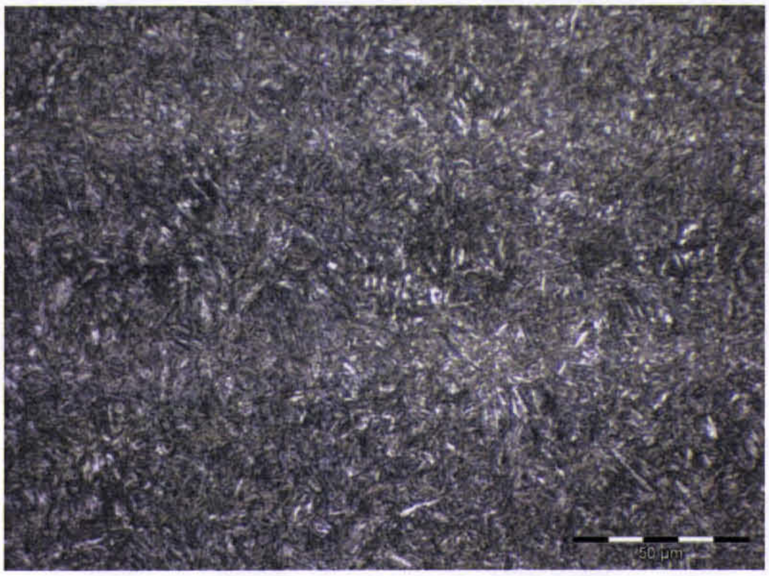

Figure 11 Base material microstructure for bolt 4 a in Figure 3. Polished specimen etched in Nital.

2.3 Reference bolts

In order to reveal if the bolt quality of the failed bolts were similar to other bolts in production, three reference bolts were received for comparison. Cross sections were made through the bolts for metallographic investigation. Figure 12ab shows overview pictures of the cross section through reference bolt threads. The pictures reveal the presence of an imperfection at the thread top, and an uneven distribution of the corrosion protective layer. A picture of a thread root at higher magnification is shown in Figure 13, the attached EDS spectrums identifies the presence of an oxide layer at the coating base material interface, chromium particles at the grain boundaries in the base material towards the thread surface and a zinc based corrosion protective layer. The corrosion protective layer was unevenly distributed and features showing possible crack initiations were observed at some thread roots, as shown in Figure 14. A cross section through this area was made and a crack initiation was readily observed as shown in Figure 15. The microstructure of the bolt is shown in Figure 16, showing a structure consisting of tempered martensite. The bulk hardness was measured to be 41 HRC.

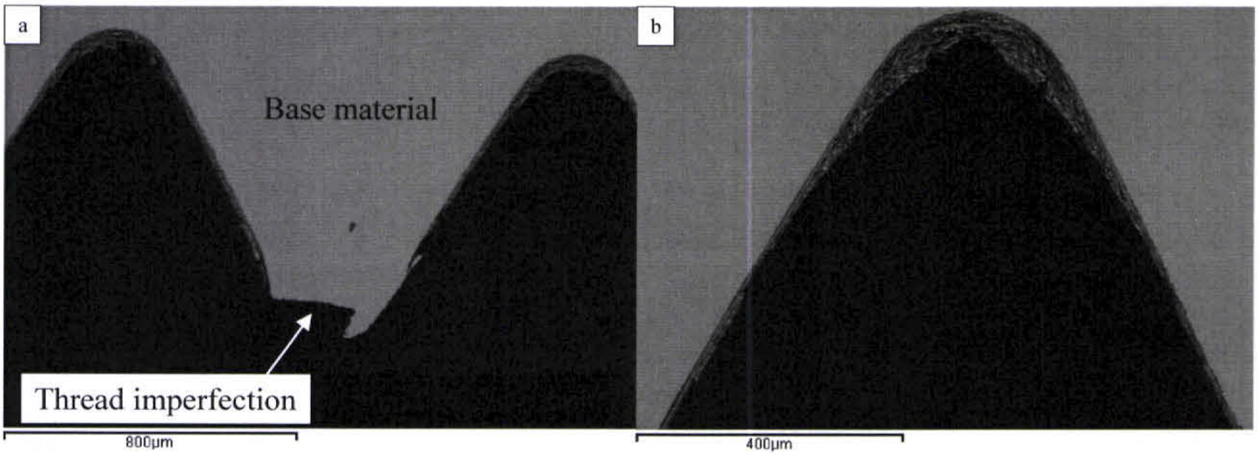

Figure 12 Overview picture in SEM of cross section through threads. a: Picture of thread imperfection. b: Picture showing uneven distribution of coating.

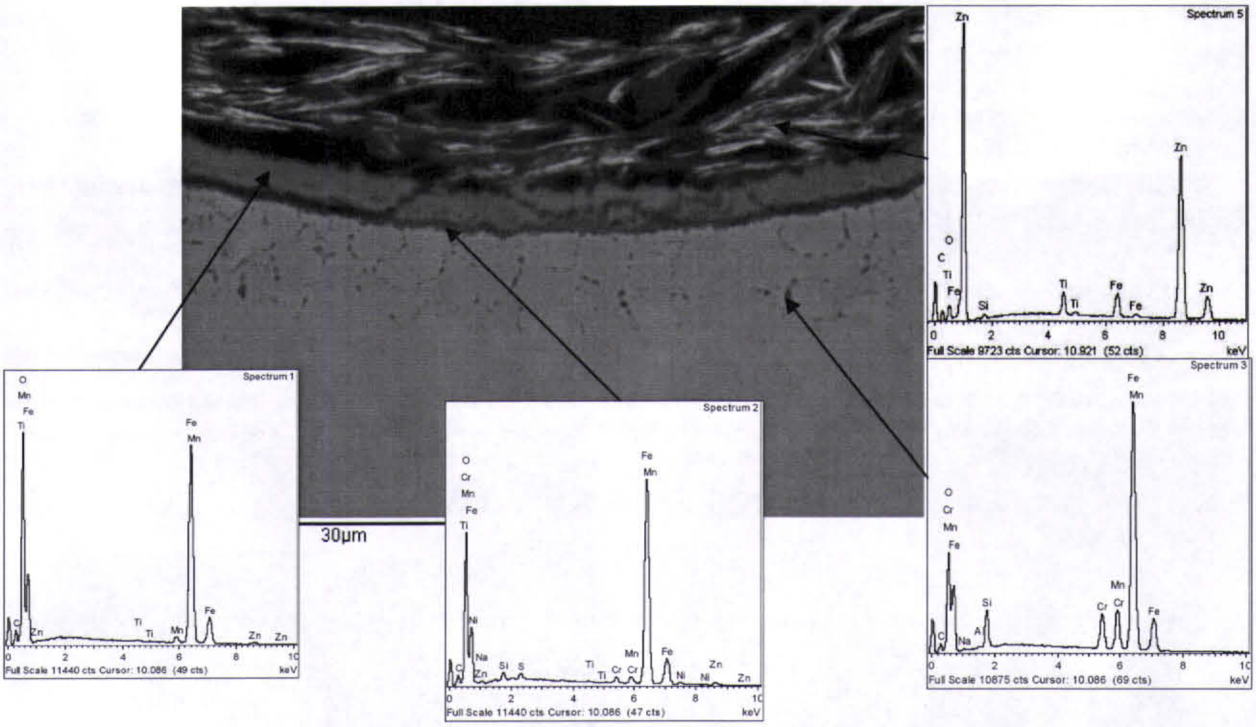

Figure 13 Picture of cross section though reference bolt. The attached EDS spectrums show: Spectrum 1 and 2 Oxides at the coating/base material interface. Spectrum 3 Chromium rich particles along grain boundaries. Spectrum 5 Zinc based corrosion protective coating.

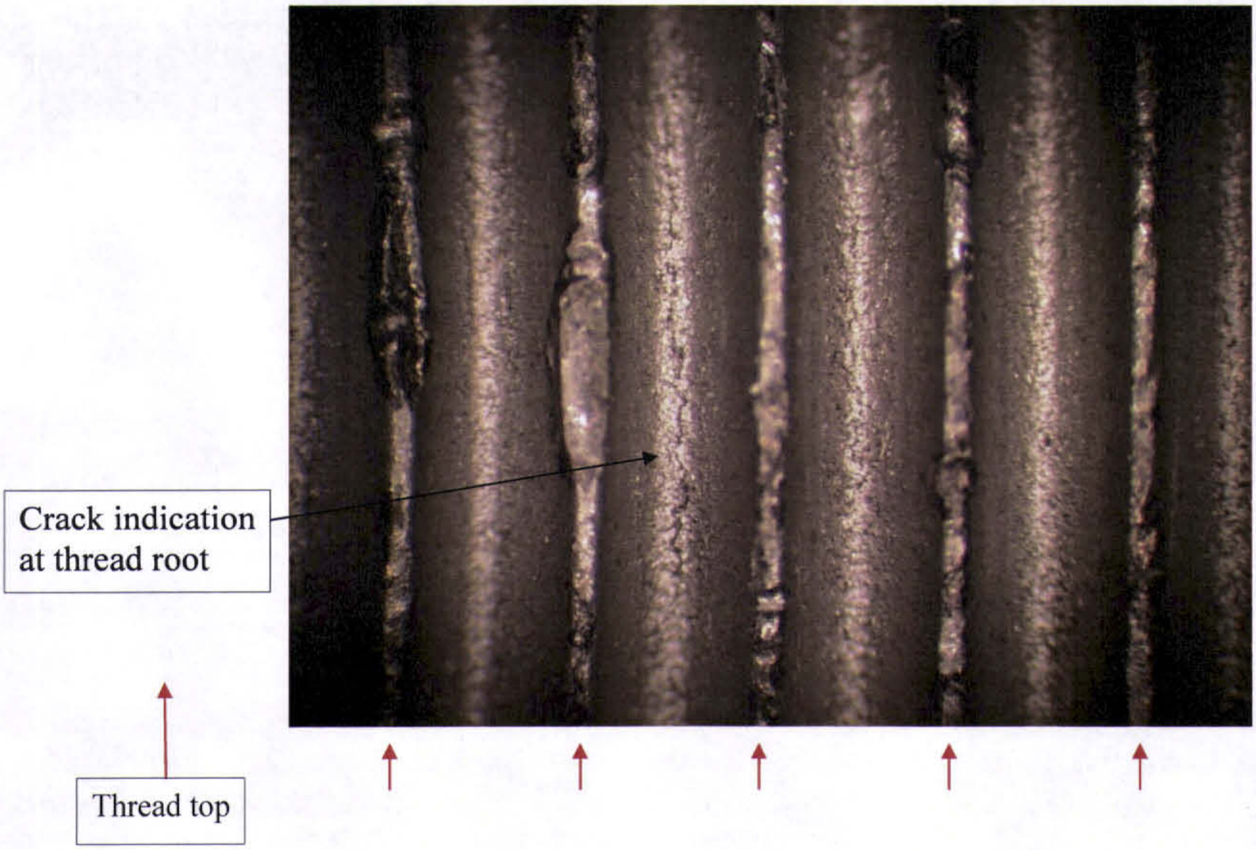

Figure 14 Picture in stereo light microscope of thread with crack indication. Thread tops are identified by red arrows.

Figure 15 Cross section through the area with crack indication at thread root as observed in SEM.

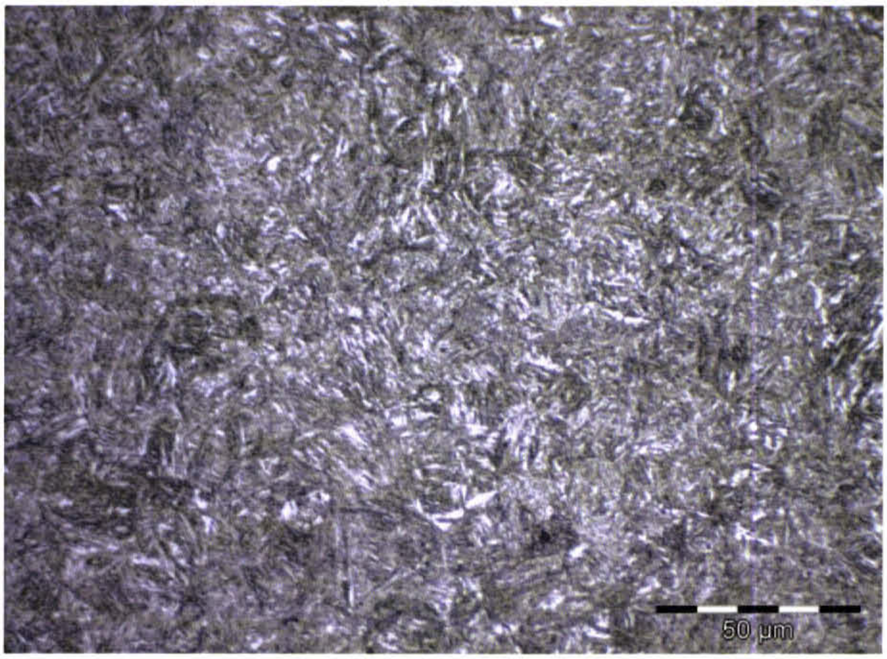

Figure 16 Microstructure of reference bolt. Polished sample etched in Nital.

3 Conclusion

Based on the obtained results the following is concluded:

The bolt quality is in general questionable as both the failed bolts and the received reference bolts shows irregularities as uneven coating distribution, oxides at the coating/bolt interface, intergranular chromium particles towards the bolt surface and crack initiations. The true cause for the observed deviations must be established. Quality and process control procedures should be revised.

The later parts of the bolt crack propagations are due to fatigue. The final fracture, when observed is very small and indicates low loading at the time of the final fracture. In order to explain the intergranular fracture surfaces observed at the crack initiation areas a fracture mode including stress corrosion cracking and corrosion assisted fatigue can not be excluded. Although the amount of branching that would be expected in the case of stress corrosion cracking is questionable, other explanations for the observed secondary cracking has not been established. The intergranular features observed along with the fatigue crack propagation could be related to high stress amplitudes. However, the very small ductile final fractures observed, does not support this mode, and corrosion assisted fatigue seems to give a more sound explanation.
Corrosion assisted fatigue would increase the cack propagation speed thus resulting in development of a critical failure over a short period of time as observed in the given case.

In order to obtain the true mode for the observed failure experimental work including corrosion, strain and fatigue testing must be performed. Such testing has not been in the scope of the current investigation.

Appendix 1

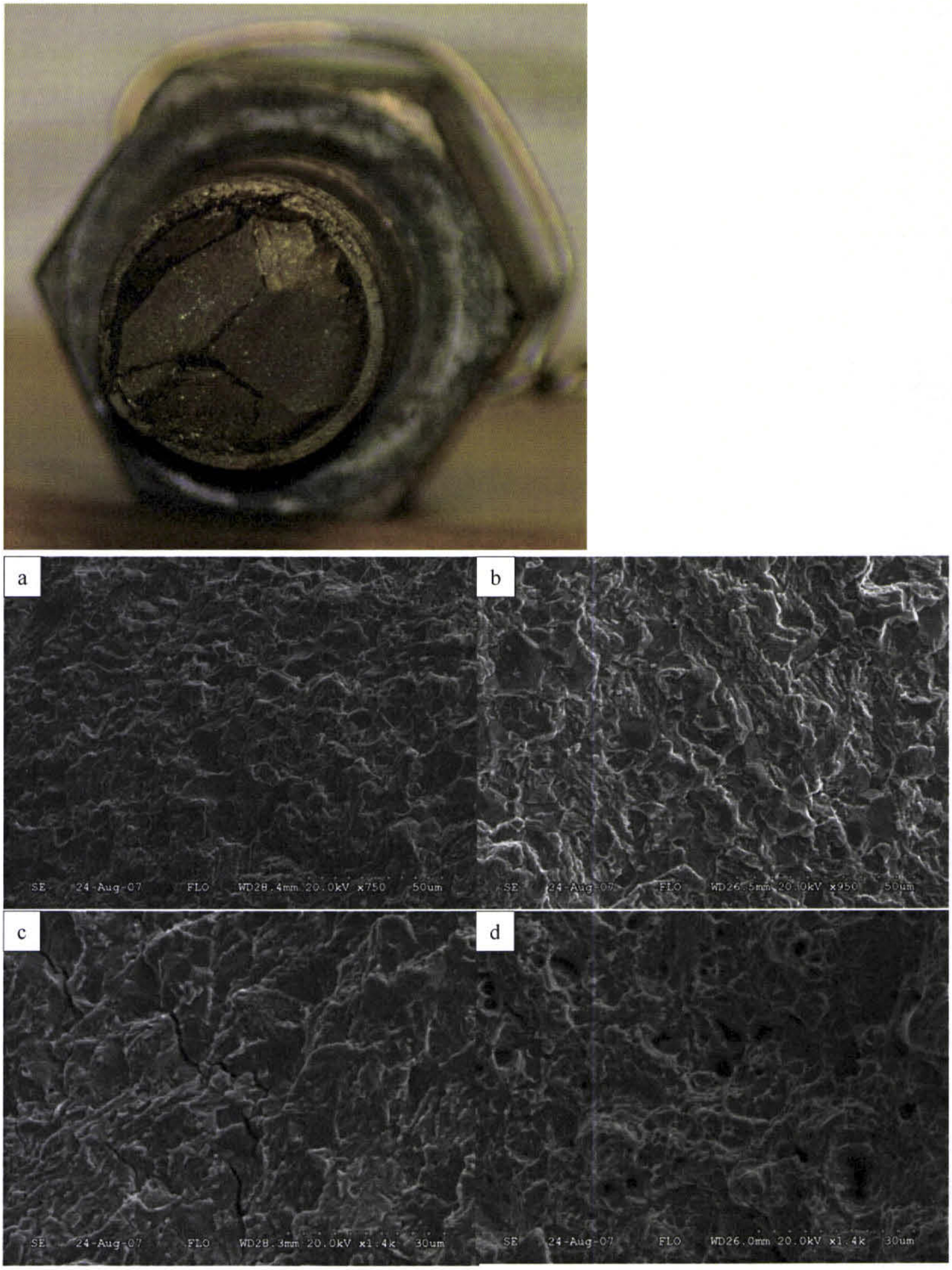

Figure 17 Representative pictures from fracture surface Bolt 1.

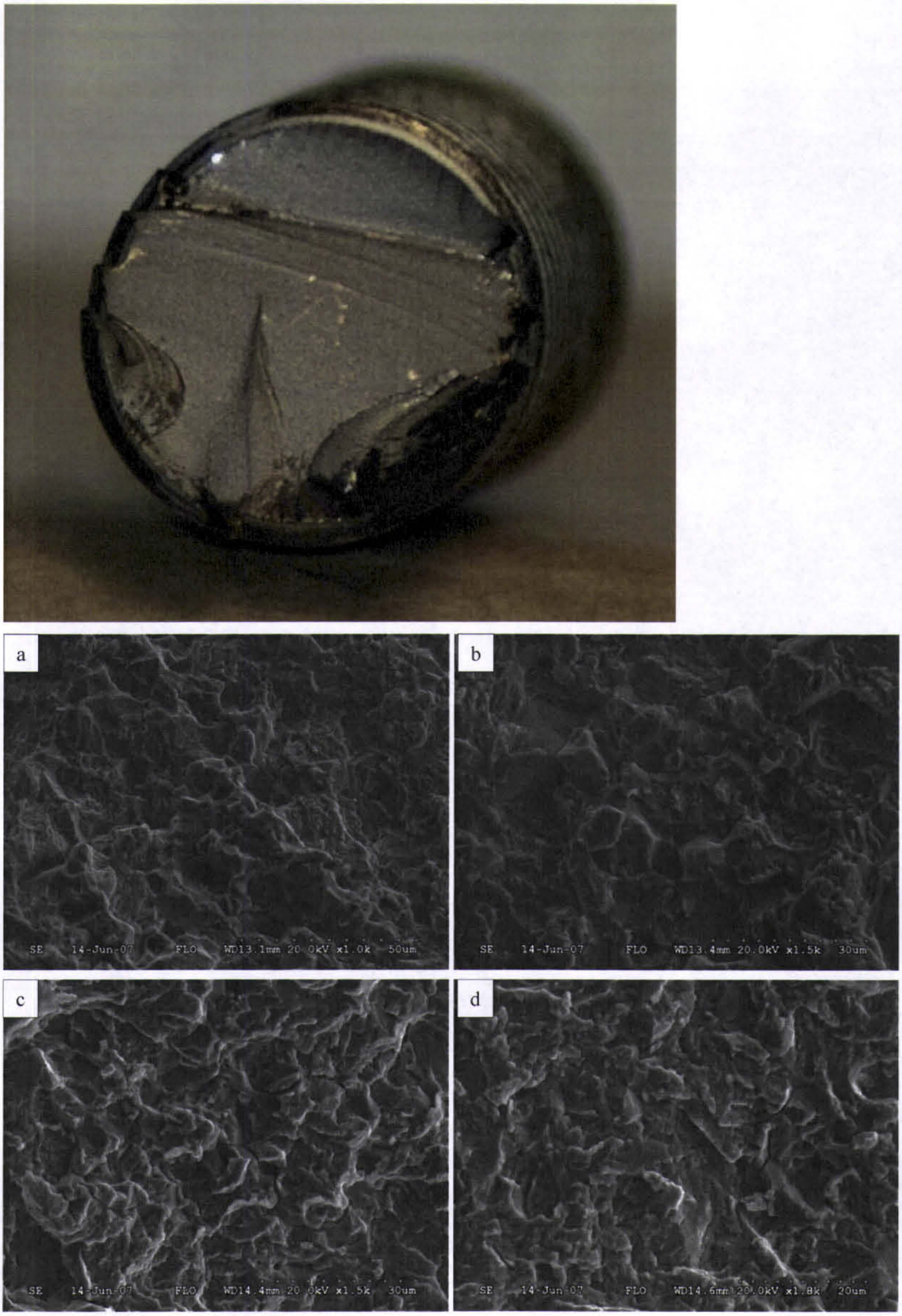

Figure 18 Representative pictures from fracture surface Bolt 2.

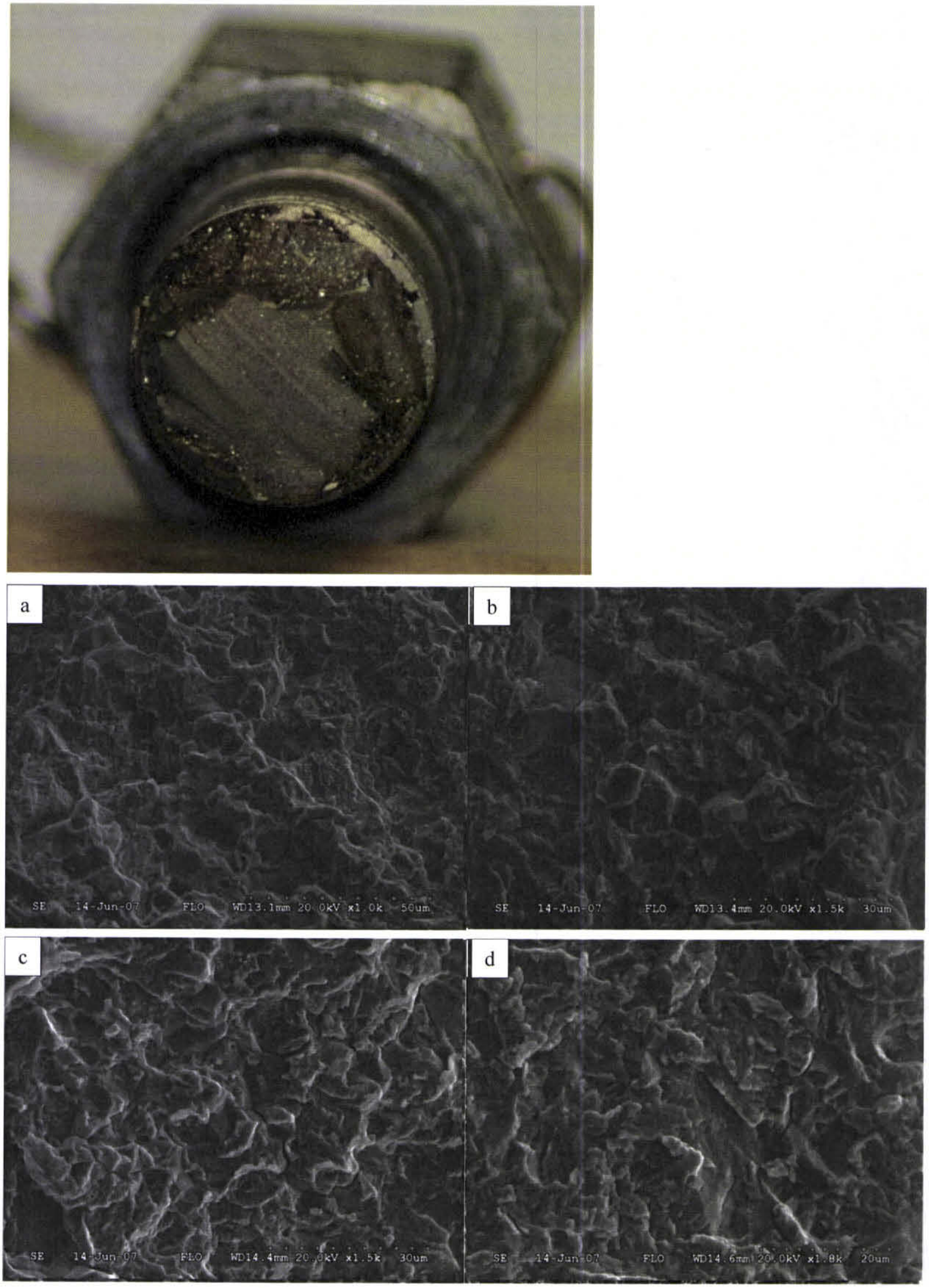

Figure 19 Representative pictures from fracture surface Bolt 3.

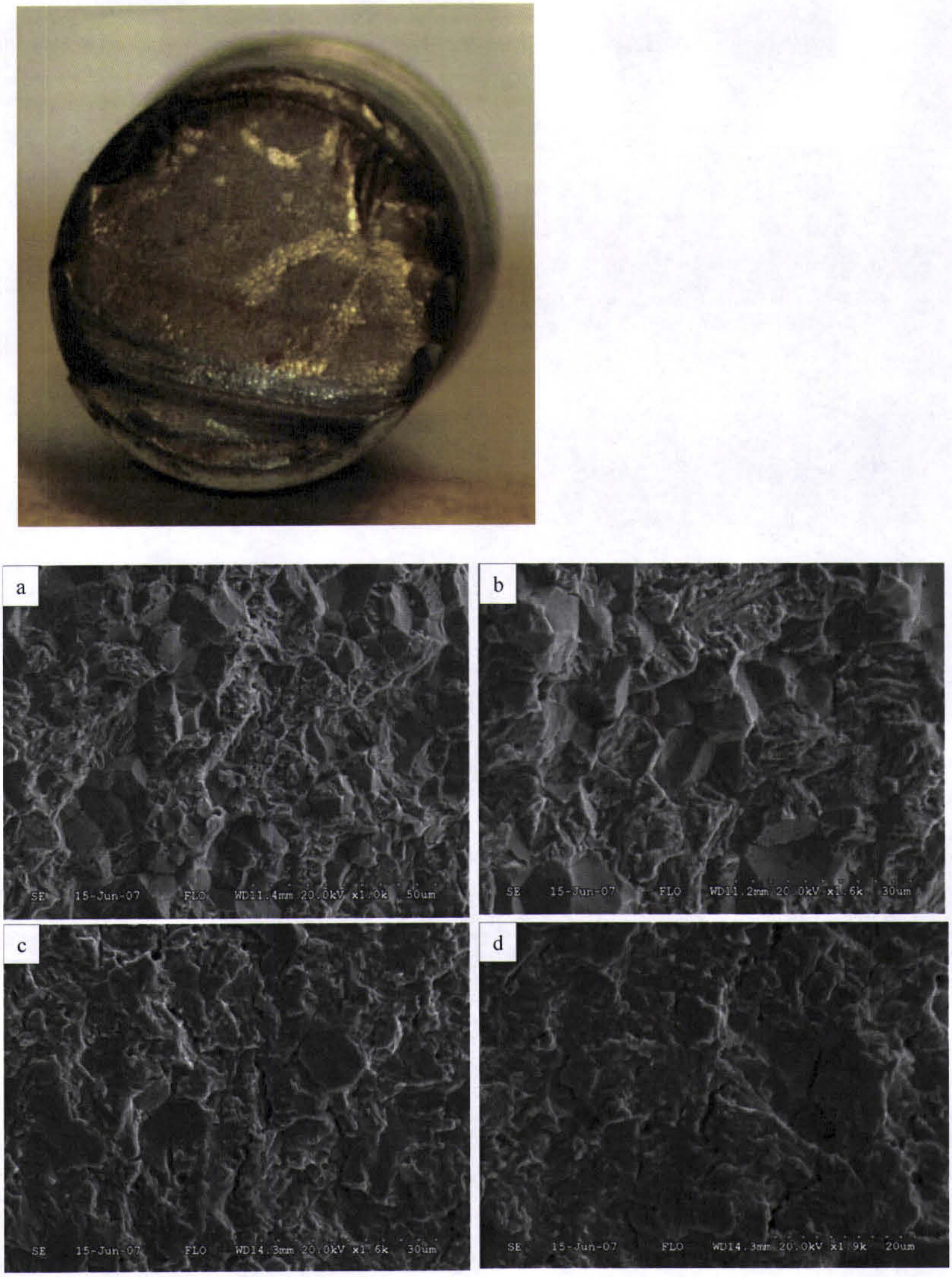

Figure 20 Representative pictures from fracture surface Bolt 4.

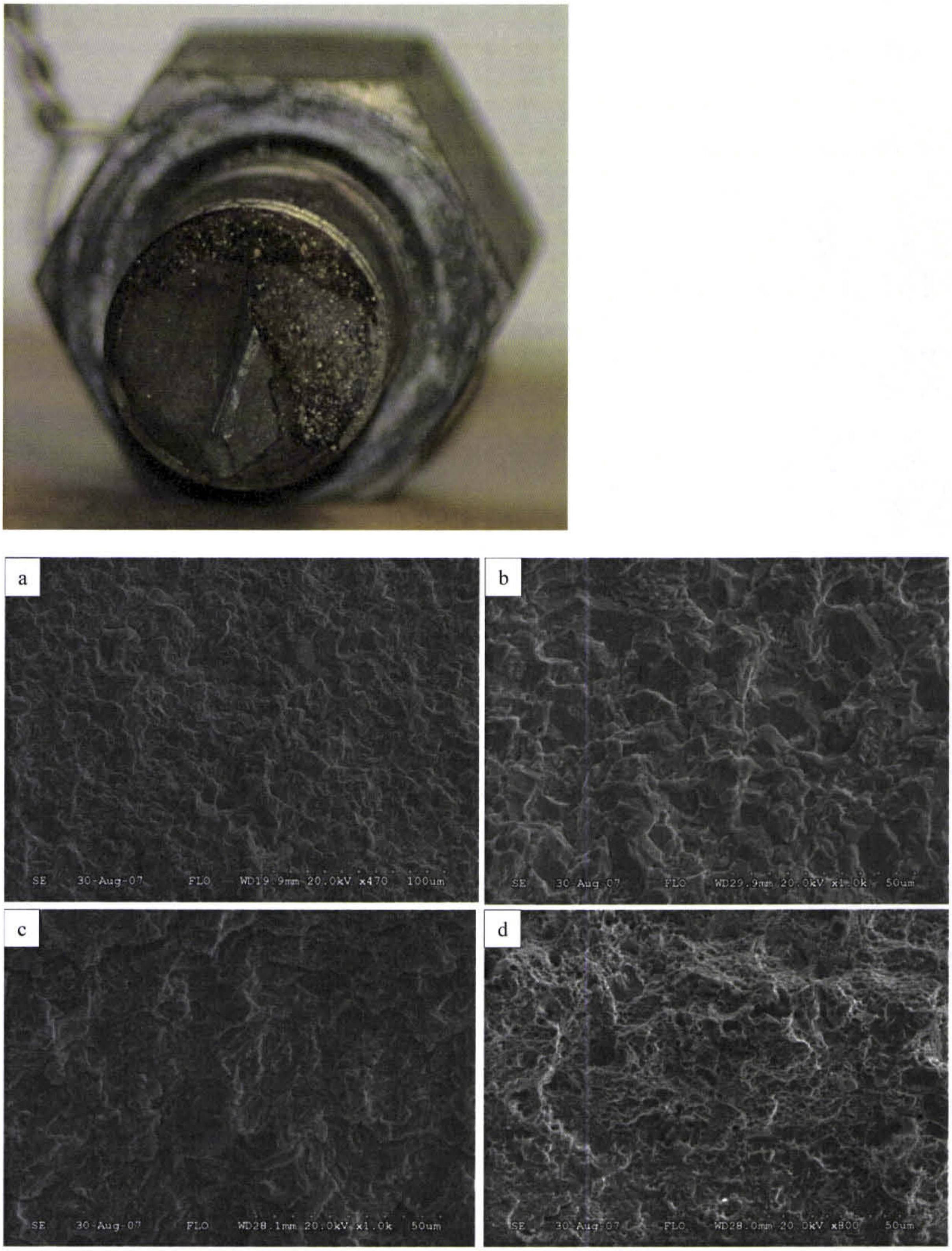

Figure 21 Representative pictures from fracture surface Bolt 5.

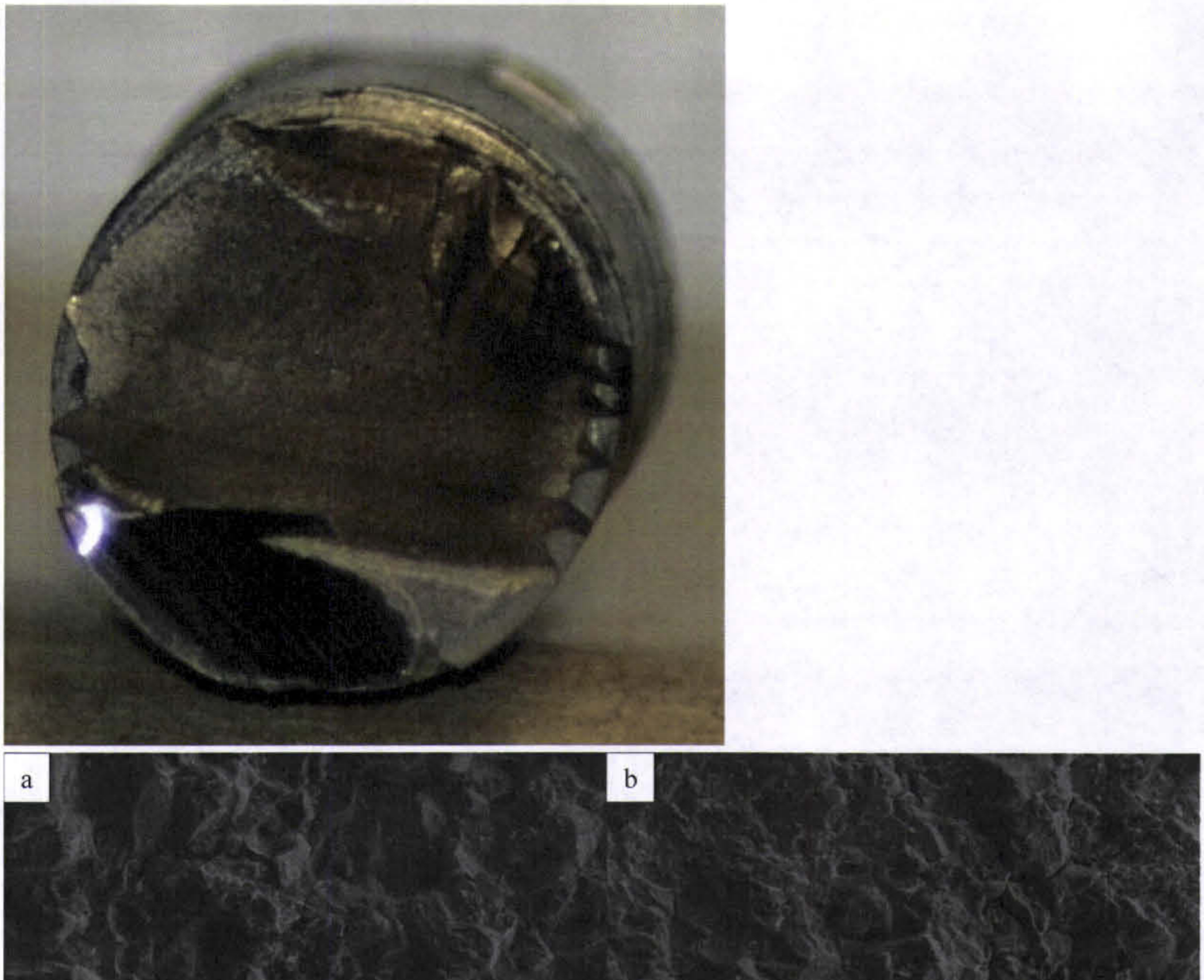

Figure 22 Representative pictures from fracture surface Bolt 6.