



Australian Government
Australian Transport Safety Bureau



TECHNICAL ANALYSIS REPORT 17/03

Bolt Fracture High Pressure Turbine Disk Assembly

**Pratt & Whitney Canada PW118A
Engine s/n 115120**

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1. INTRODUCTION

Airnorth Regional experienced operational problems with a Pratt and Whitney Canada PW118A engine (engine s/n PC-E 115120). The problems ranged from hung starts resulting in aborted hot starts to vibration (sub-idle vibration) and noise from the high pressure (HP) rotor. These problems occurred over a period of several days. In order to resolve the problems the engine was removed from the aircraft to allow further investigation through disassembly.

Disassembly revealed that the bolted joint between the HP turbine disk and turbine stub shaft had failed. Of the five bolts used in the assembly, two had fractured in the threaded section. The remaining three bolts exhibited varying degrees of bending and thread damage.

After a detailed examination of the bolts by Pratt and Whitney Canada, it was concluded that the fracture of the two bolts and cracking in the remaining bolts was caused by corrosion fatigue, with sulphur being identified as the corrosive agent. It was proposed that the presence of sulphur was the result of environmental contamination¹.

Airnorth brought the bolt failure and subsequent analysis by the engine manufacturer to the attention of the ATSB. An independent review of the bolt failure analysis was undertaken by the ATSB.

2. TURBINE BOLT HISTORY

Previous failures of the turbine bolts have involved the initiation and growth of fatigue cracks from the fillet between the shank and head. Service Bulletin, P&WC S.B. No. 20498R1, revision 1, Apr 08/91, introduced a program of bolt modification/rework to minimise the magnitude of stress under the bolt head by increasing the fillet radius. The bolts from engine s/n 115120 were identified with part number 3119838-02, the correct part number for new bolts post service bulletin 20498R1.



Figure 1. One of the turbine bolts from engine s/n 115120 head showing the part number on the bolt head.

¹ Pratt&Whitney Canada Engine/Component Investigation Report, Report No. TO28252

The bolts had been installed during a hot section inspection². The engine had completed 2995.8 hours (3054 cycles) since overhaul prior to the investigation of operational problems.

The design features of the bolts, post service bulletin 20498R1, are consistent with the minimisation of sites of stress concentration. The bolts were manufactured from a nickel alloy (alloying additions identified by energy dispersive Xray analysis comprised chromium, cobalt, titanium, molybdenum and iron). The chemical composition of the bolts was reported³ to be consistent with the engine manufacturer's proprietary specification CPW439.

3. EXAMINATION OF PHYSICAL EVIDENCE

Two of the bolts had fractured in a location generally consistent with the bearing face of the installed nut. The remaining three bolts had been damaged by the process used to remove the nuts. These bolts exhibited some thread root cracking but had not fractured, see figure 2. A metallographic specimen had been prepared from one of the intact bolts.



Figure 2. The turbine bolts as received. The bolts had been identified A through E (arranged left to right in the figure).

² Pratt&Whitney Canada (A'Asia) Summary and Condition Report, Work Order No.24182, 20-Sep-1999

³ Pratt&Whitney Canada Engine/Component Investigation Report, Report No. TO28252

Fatigue crack initiation and growth caused the fracture of the two bolts, see figure 3. The features of the primary fatigue initiation sites were obliterated by the mechanical effects of the progressive loss of structural integrity of the turbine assembly and/or the processes required to remove the bolts from the assembly.

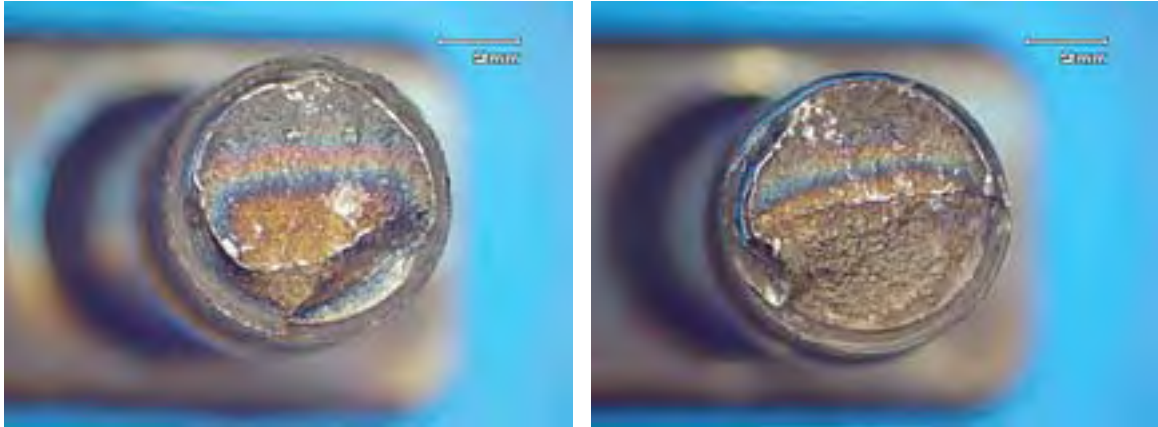
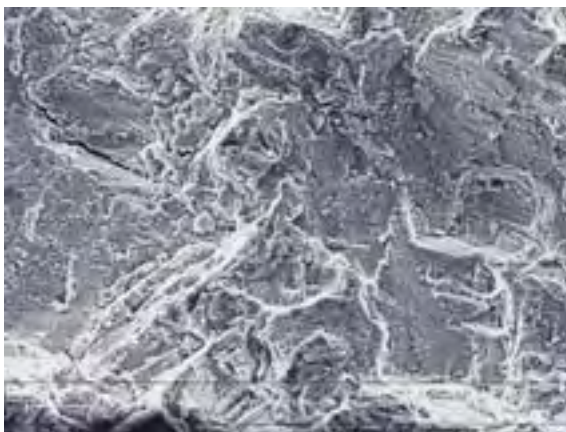


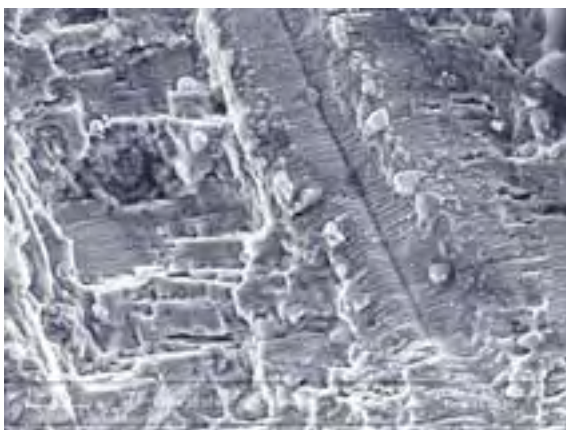
Figure 3. The fatigue fracture surfaces of bolts A (left) and B (right). The interference colours on the fracture surfaces indicate a gradation in oxide film thickness on the fracture surfaces, from thick at the fatigue crack origin, to thin at the final fracture zone.



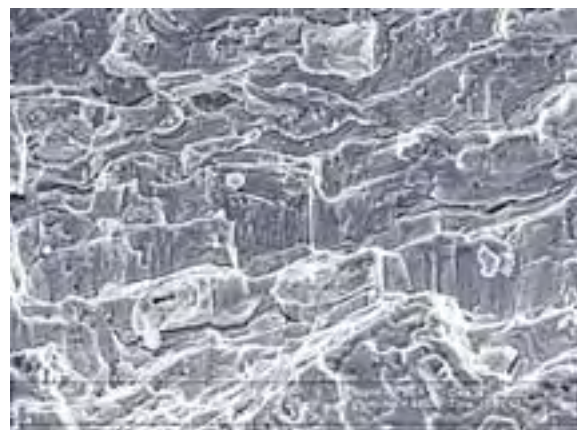
Bolt A, near the fatigue origin



Bolt A, central region of the bolt



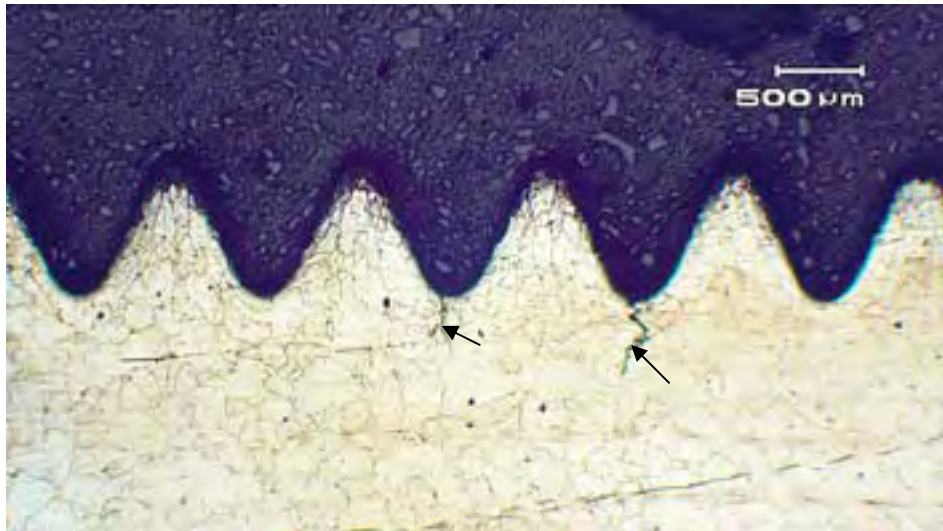
Bolt B, near the origin



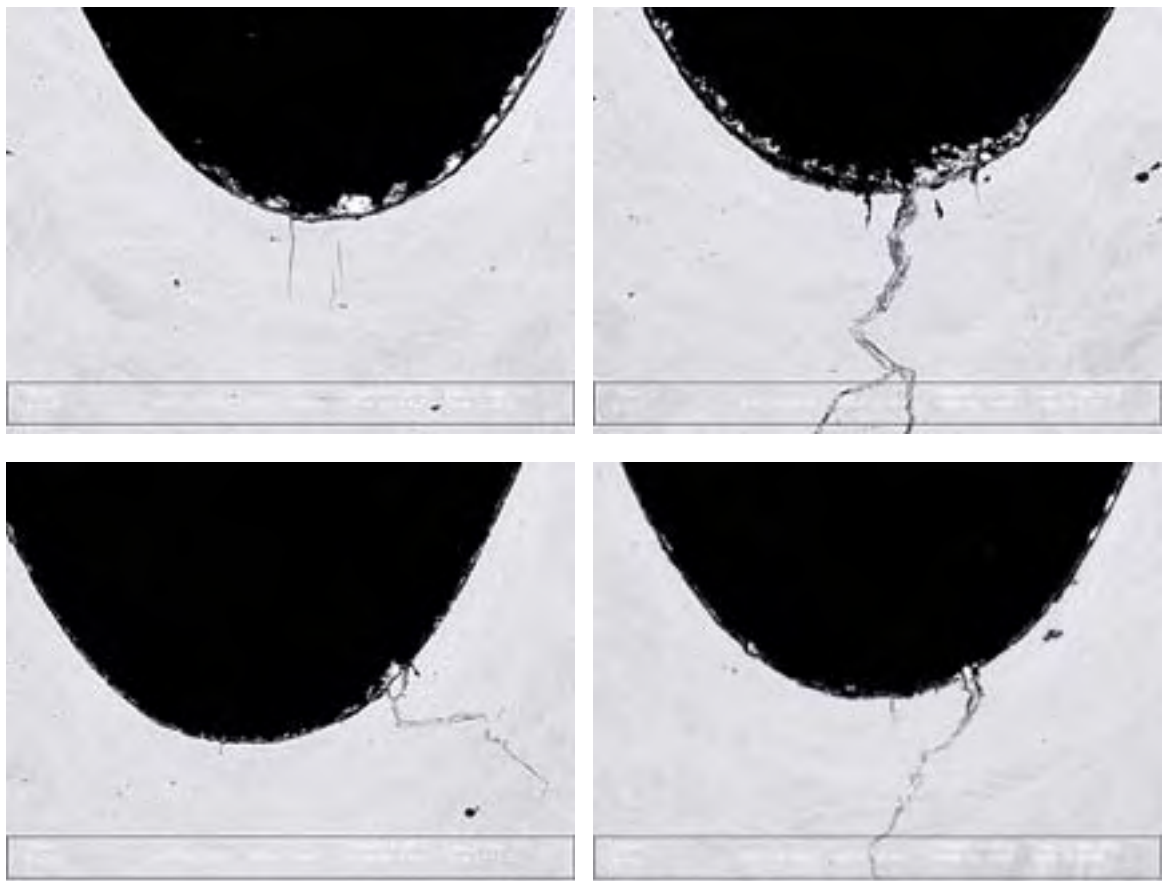
Bolt B, central region of the bolt

Figure 4. Scanning electron micrographs showing typical features of the fatigue fractures, bolts A and B.

It was apparent from an examination of the metallographic specimen that crack-like defects had been created in the thread roots by a corrosion cracking mechanism, see figure 5.



(a) Metallographic section as received from PW&C



(b) Scanning electron micrographs of the metallographic section after repolishing by ATSB showing the nature of cracking in adjacent threads.

Figure 5. Metallographic section taken through the threaded section of bolt D by PW&C

4. ANALYSIS OF BOLTED JOINT FAILURE

There are two locations of stress concentration in a tightened bolt, the transition from head to shank and the thread just inside the bearing face of the nut. Normally the effect of these regions of stress concentration on the fatigue strength of bolts is minimised by establishing the correct level of preload in the bolt and by ensuring that the geometric detail of the bolt to shank radius and the thread root radius minimises stress concentration. The development of crack-like defects in a region of stress concentration in a bolt (the thread adjacent to the bearing face of the nut) increases the local stress level and will make fatigue crack initiation likely for bolts subjected to alternating loads.

Detailed examination of the crack-like defects in the metallographic section revealed that the defects were filled with a mixture of oxide and silver, see figure 6. The elements sulphur and silver were detected on the thread surface.

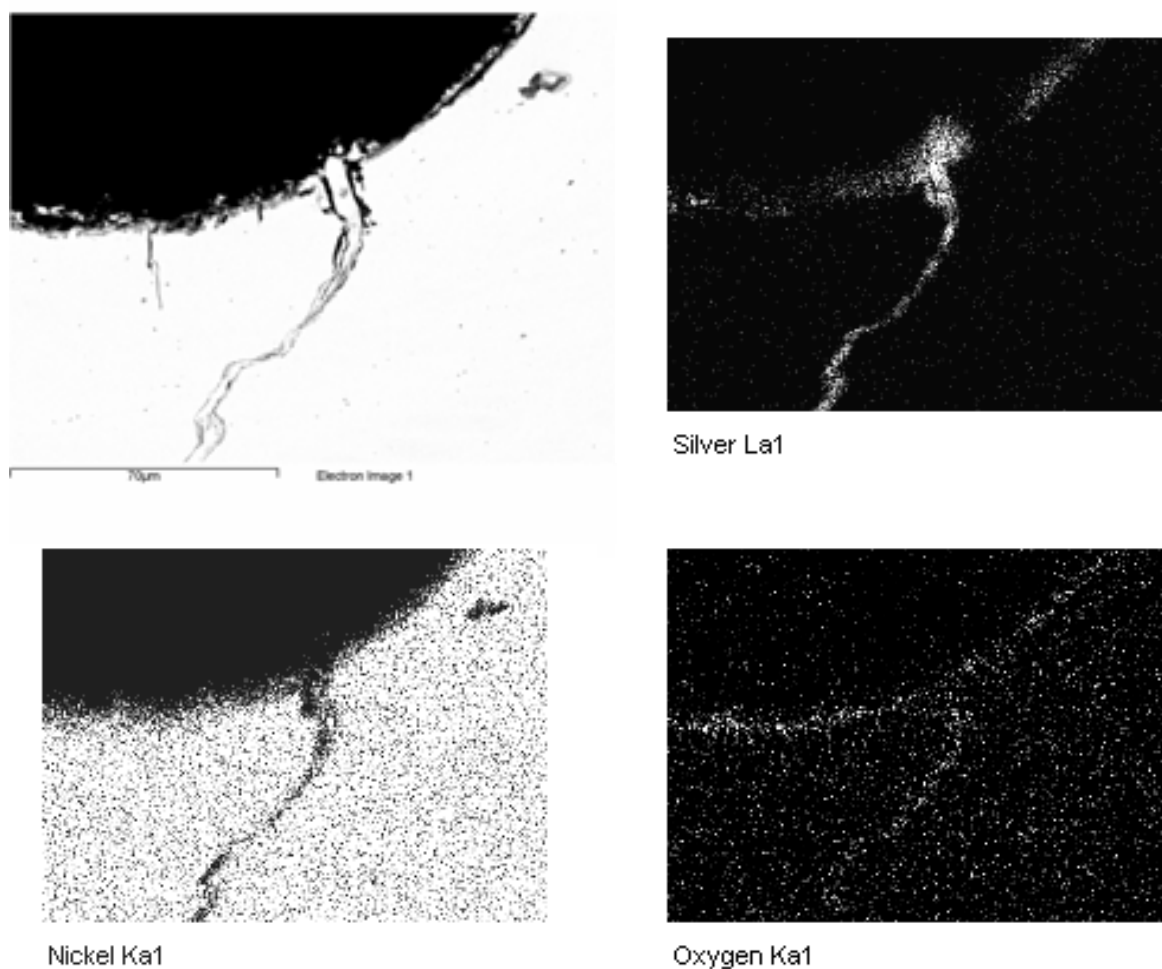


Figure 6. Xray analysis elemental distribution maps for nickel silver and oxygen. The image shown, upper left, is a back scattered electron image.

The PWC report concluded that element sulphur on the threaded surface was associated with a compound derived from environmental contamination. The presence of silver was assumed to be a result of the displacement of silver plating from the installed nut.

Examination of the threaded sections of all bolts revealed the presence of a compound or, the residue of a compound, on the thread surfaces under the nuts and within the bolted joint, see figure 7. The exposed region of thread within the bolted joint is not in contact with the installed nut. The region of the bolted joint is exposed only to compressor bleed air during normal operation.

4.1 Characterisation of the material on the thread surfaces

The material was greasy in nature. Fine nodular deposits of a compound containing both sulphur and silver along with silicon and carbonaceous material were apparent when the threads were examined at high magnifications in a scanning electron microscope. The silver was in a form that allowed it to penetrate the crack-like defects and be interspersed with the oxides in the defect suggesting that the silver be of a colloidal form.



Figure 7a. Bolt A



Figure 7b. Bolt B



Figure 7c. Bolt C

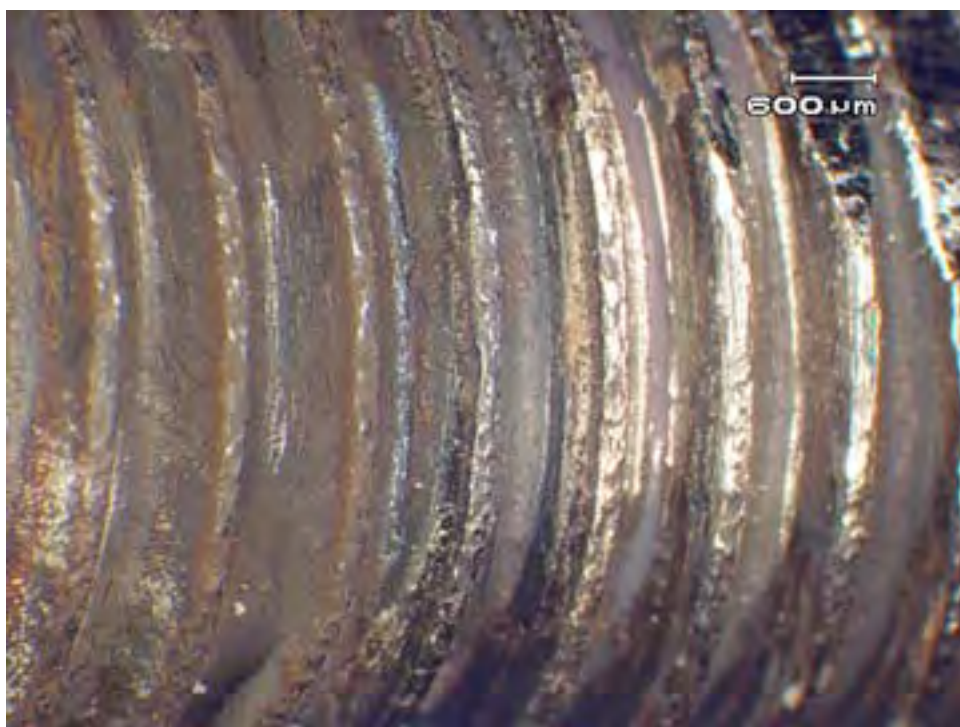


Figure 7d. Bolt C detail.



Figure 7e. Bolt E



Figure 7f. Bolt E detail.

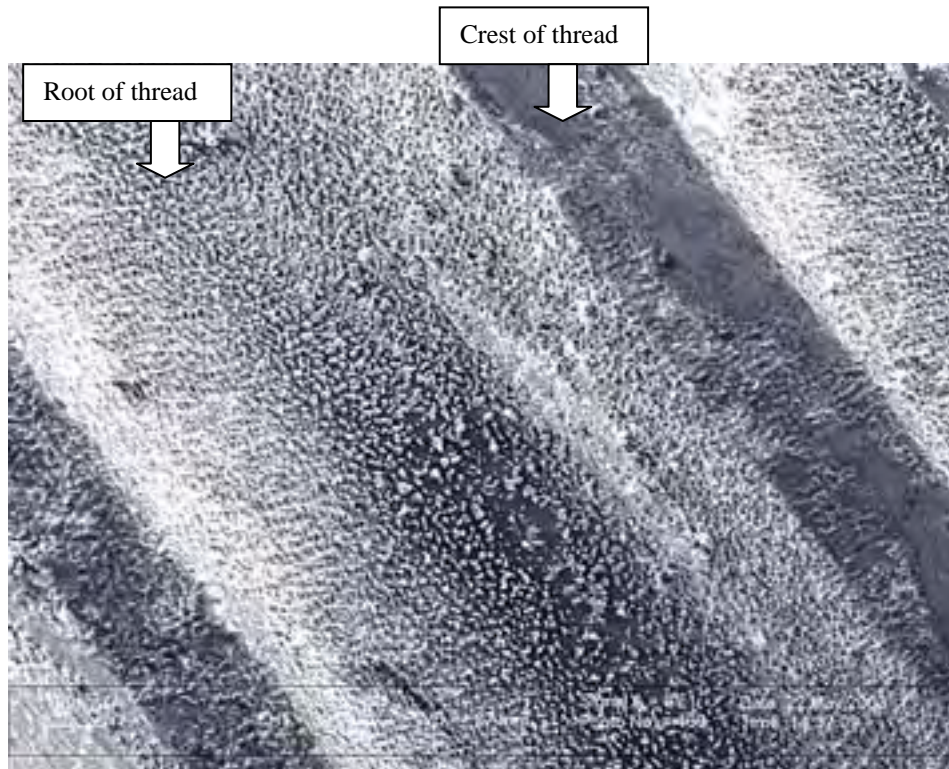


Figure 7g. Scanning electron micrograph showing the nature of thread deposits on the thread within the bolted joint

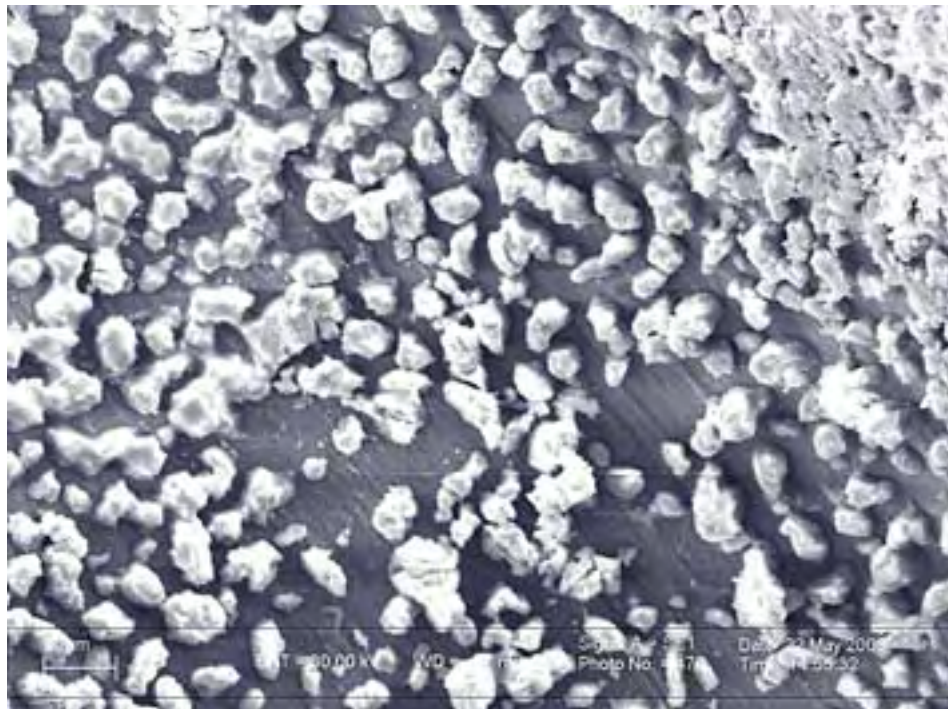
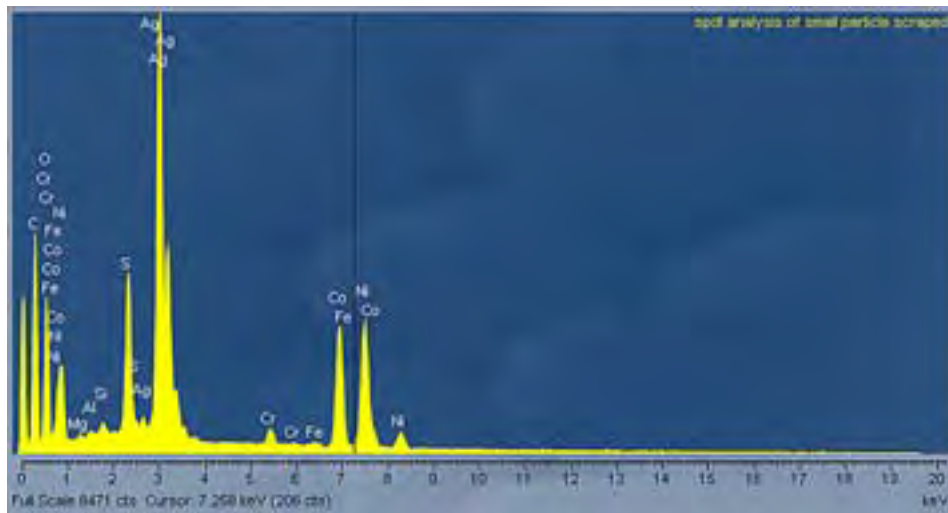
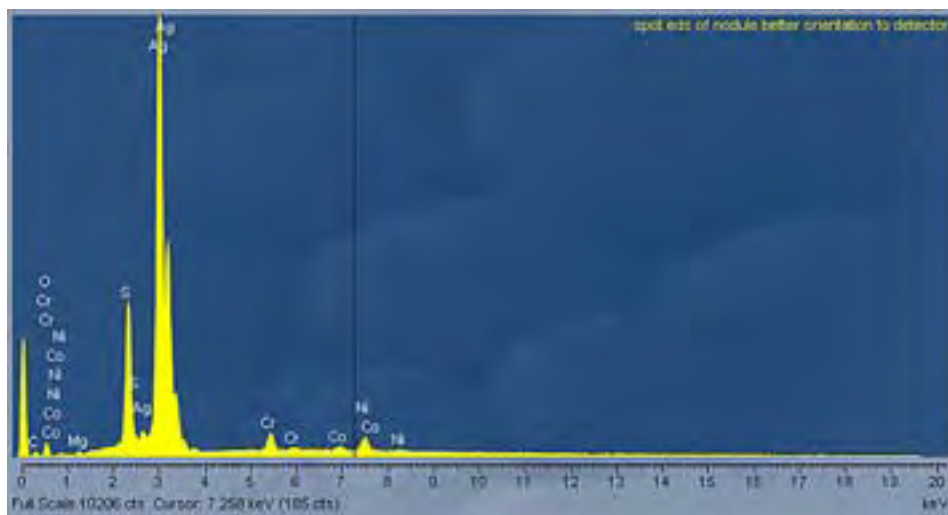


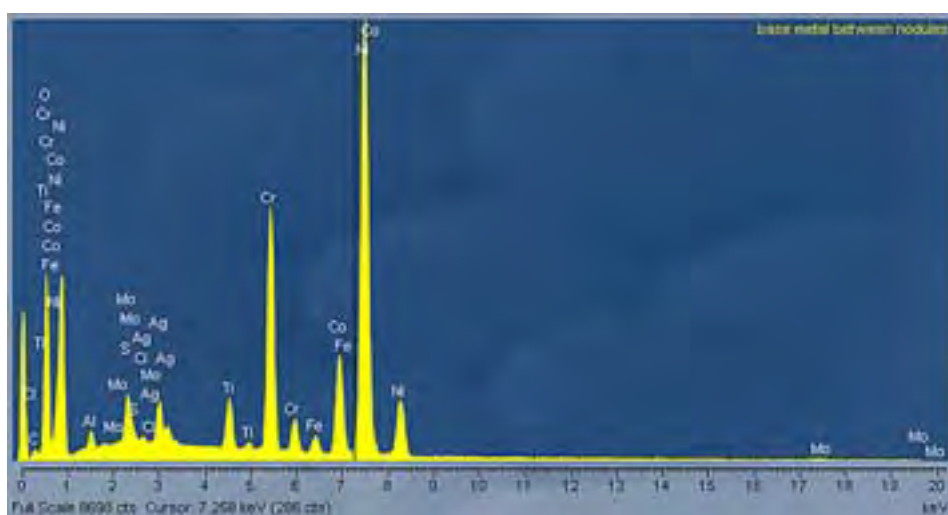
Figure 7h. Scanning electron micrograph showing the thread deposits at higher magnification.



Material scraped from bolt thread and placed on carbon stub for analysis.



Spectrum obtained from thread deposit nodule.



Spectrum obtained from thread base metal.

Figure 8. Energy dispersive X-ray spectra of thread deposits and thread base metal.

4.1.1 Examination of Bolts after Washing in Water

During the examination of the bolt threads it was noted that the residue present on the threads was not removed by washing in hydrocarbon solvents. It was found, however, that the residue was removed by washing in water, see figure 9.



Figure 8. Bolt E being agitated in distilled water. Note the reddish solute being removed from the threaded section of the bolt.

An attempt was made to identify the compounds in the thread residue by analysing the material removed by washing using Proton Nuclear Magnetic Resonance. The results of this analysis were inconclusive, probably because of the small amount of material present on the threaded section of the bolt analysed.

Examination of water washed threads in a scanning electron microscope revealed that the “greasy” material had been removed. It was notable that the oxide film formed on the thread was markedly different to that form on the remainder of the bolt, see figure 9. The oxidation resistance of nickel alloys exposed to elevated temperatures depends on the formation of a thin, tightly adherent, oxide film. The alloying additions of chromium and aluminium are made to promote this form of oxide film formation.

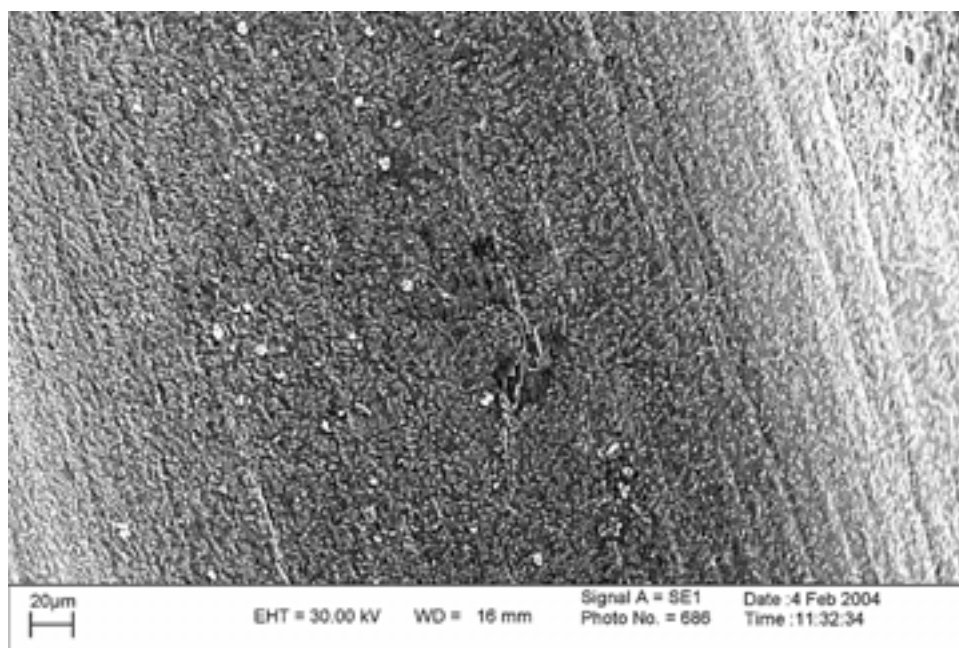


Figure 9(a) Bolt B thread runnout

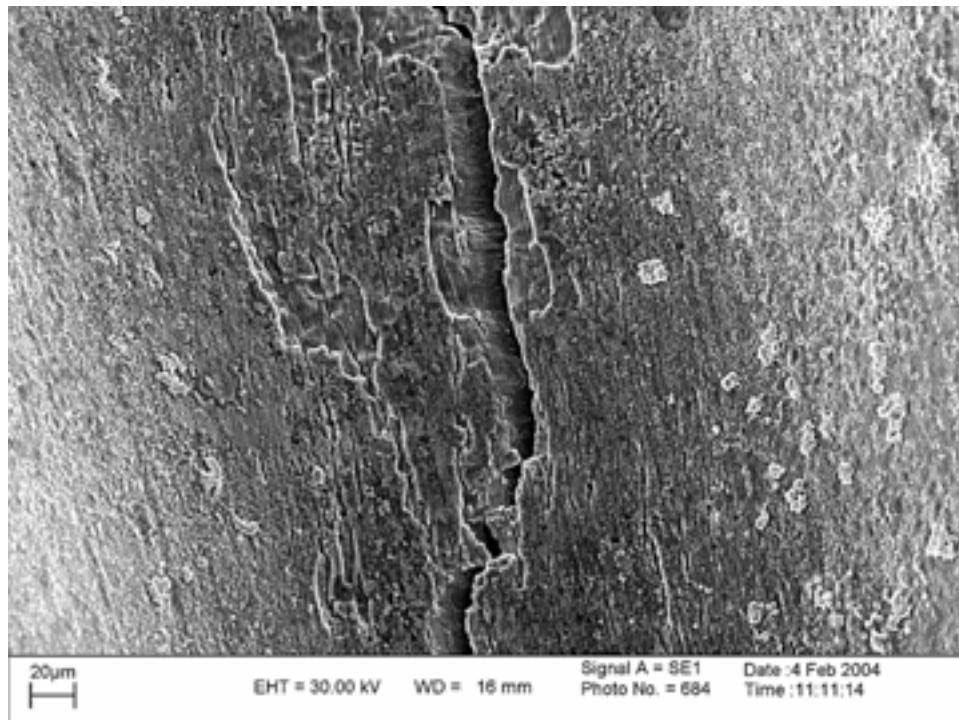


Figure 9(b) Bolt B thread root showing the nature of the oxide film and cracking from the root radius.

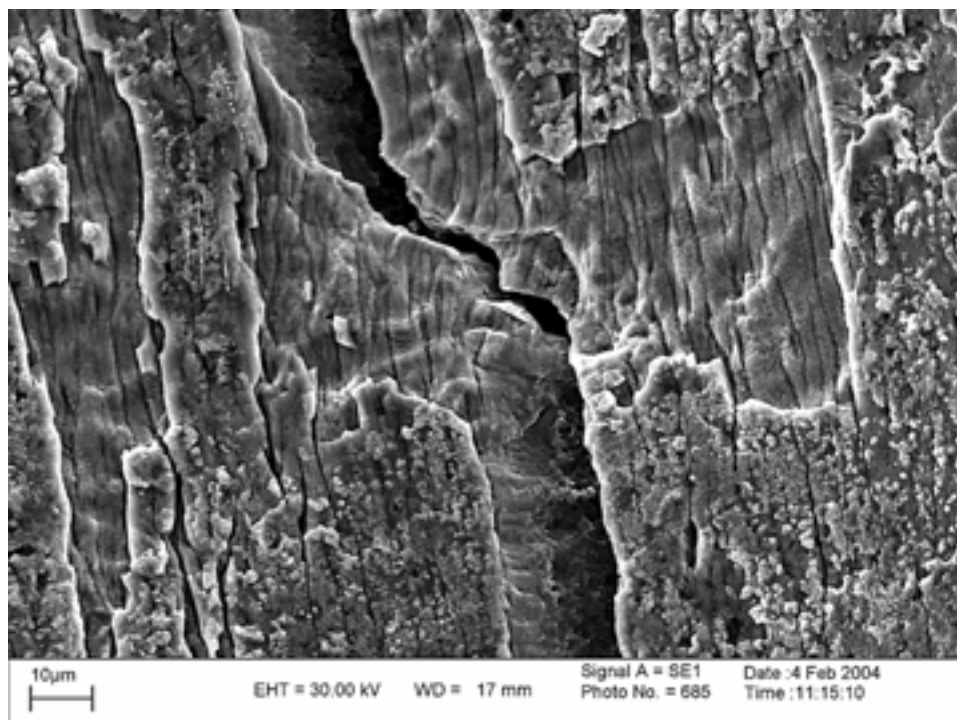


Figure 9(c) Bolt B same region, higher magnification of the field shown in (b)

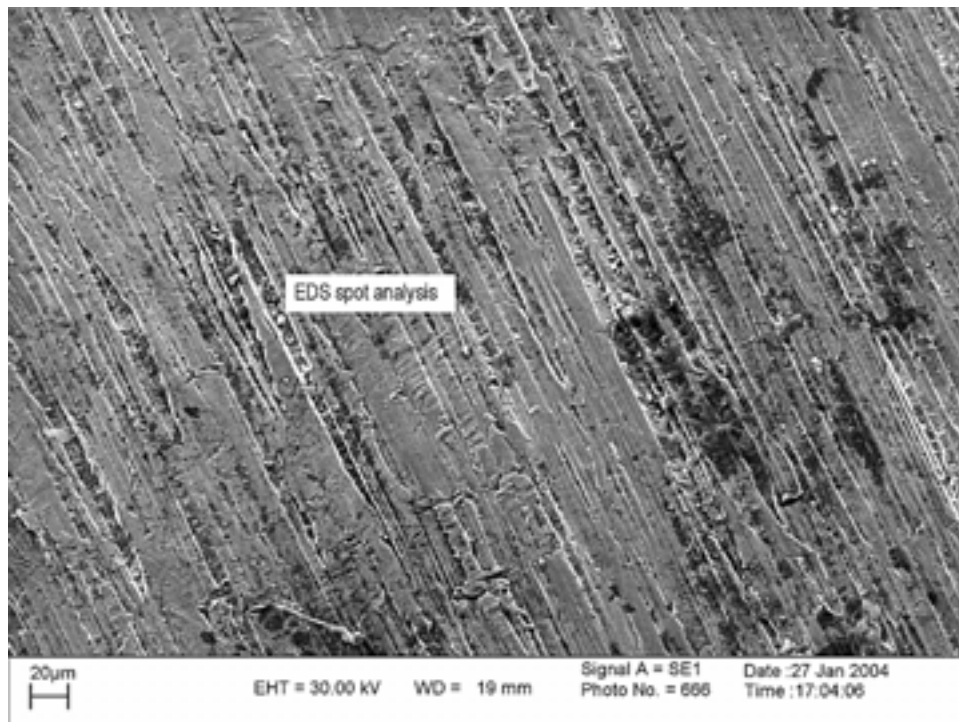


Figure 9(d) Bolt B surface of bolt shank between the two guide collars.

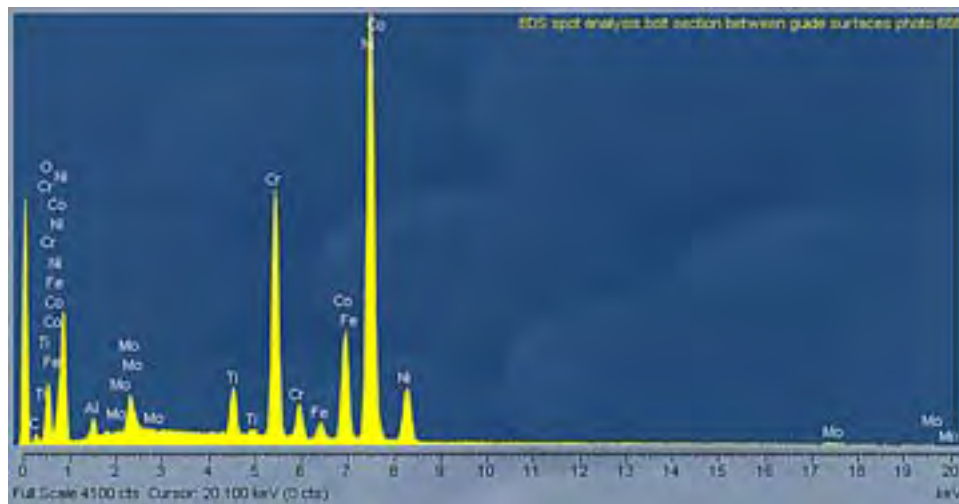


Figure 9(e). EDS spot analysis from location arrowed in fig. 9(d).

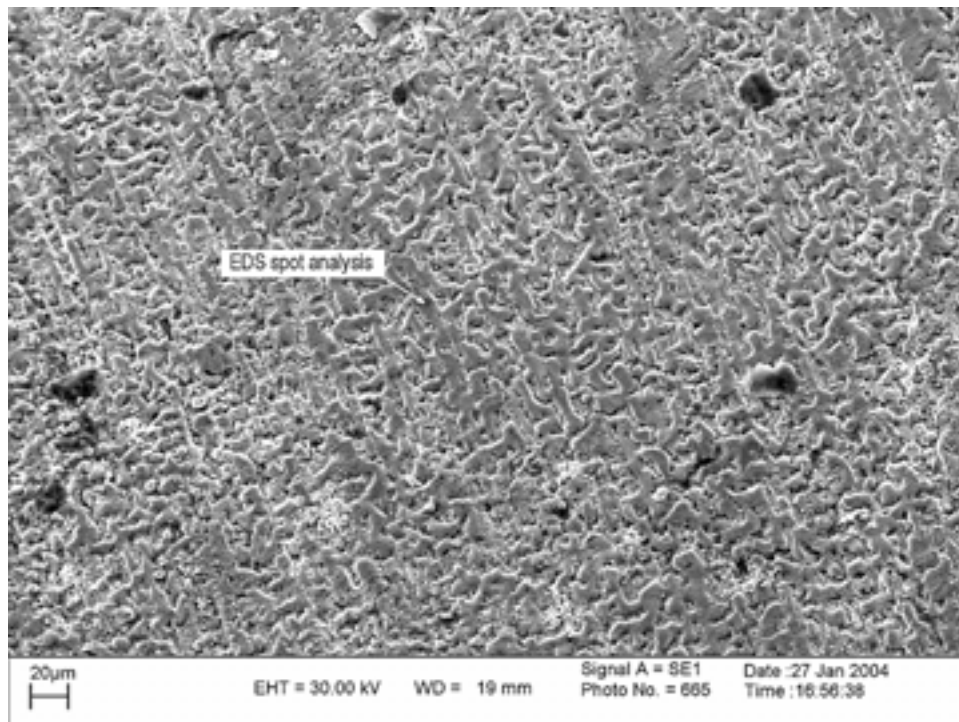


Figure 9(f). Surface of threaded region where the “greasy” residue had been present.

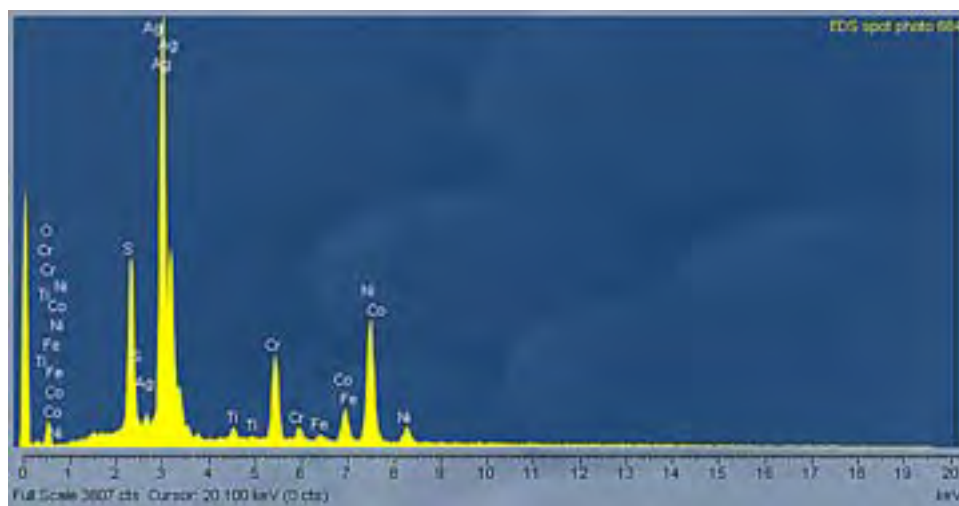


Figure 9(g). EDS spot analysis form the location arrowed in figure 9(f).

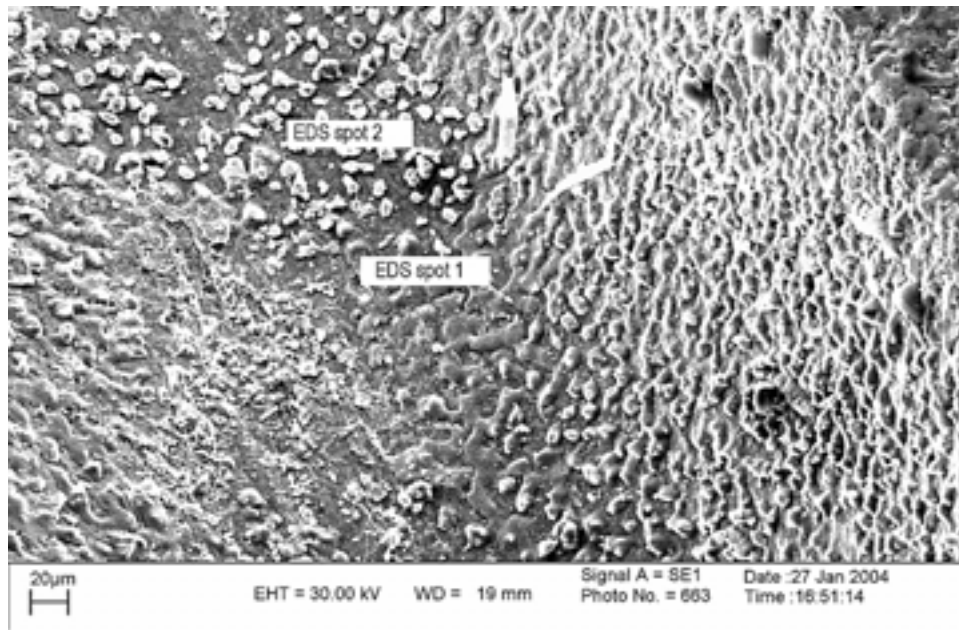


Figure 9(h). Surface of bolt thread after water washing.

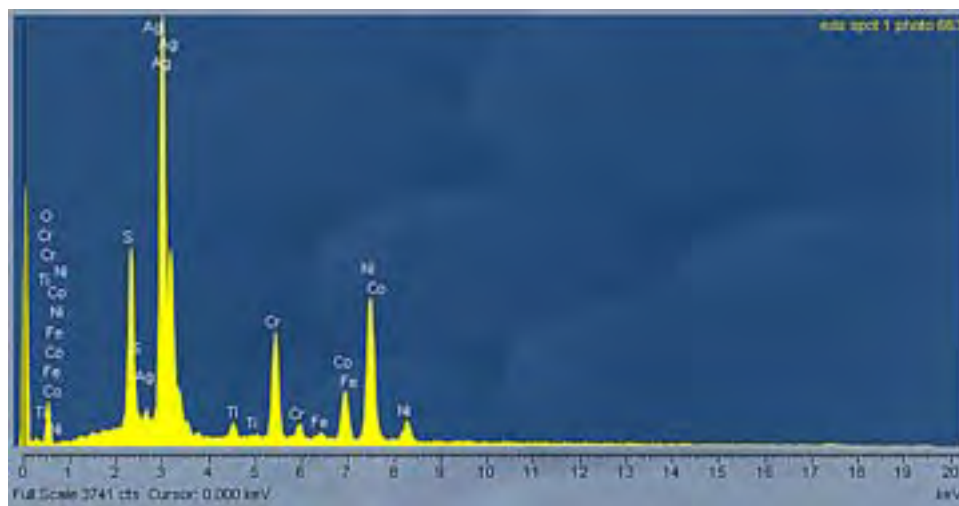


Figure 9(i). EDS spot analysis marked 1 in figure 9(h).

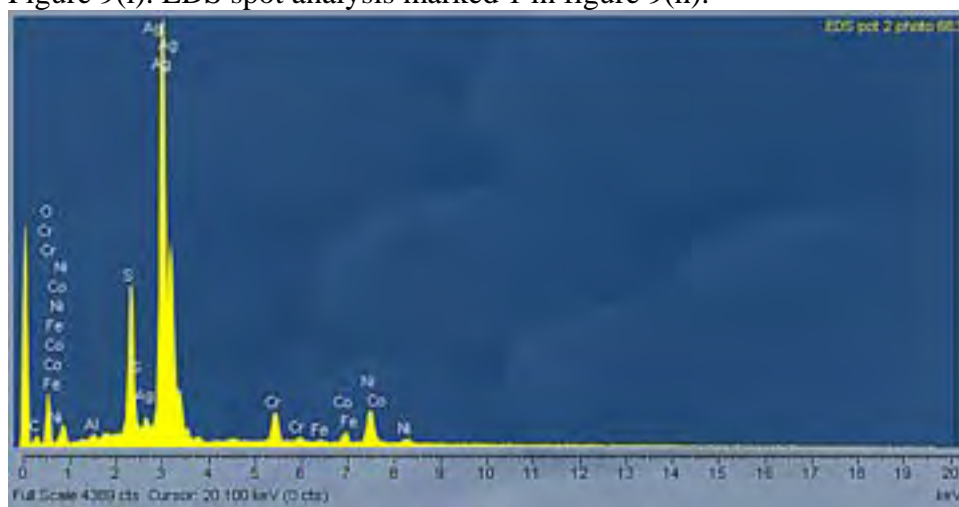


Figure 9(j). EDS spot analysis marked 2 in figure 9(h).

4.2 Nature of the Material on the Bolt Threads

The results of washing the bolts in hydrocarbon solvent and water indicate that the “greasy” residue on the bolt threads was soluble in water. Energy dispersive X-Ray analysis of material gently removed from the thread surface, by scraping with a scalpel, revealed that the elements silver and sulphur were the major constituent of the material, see figure 8 and figure 10.

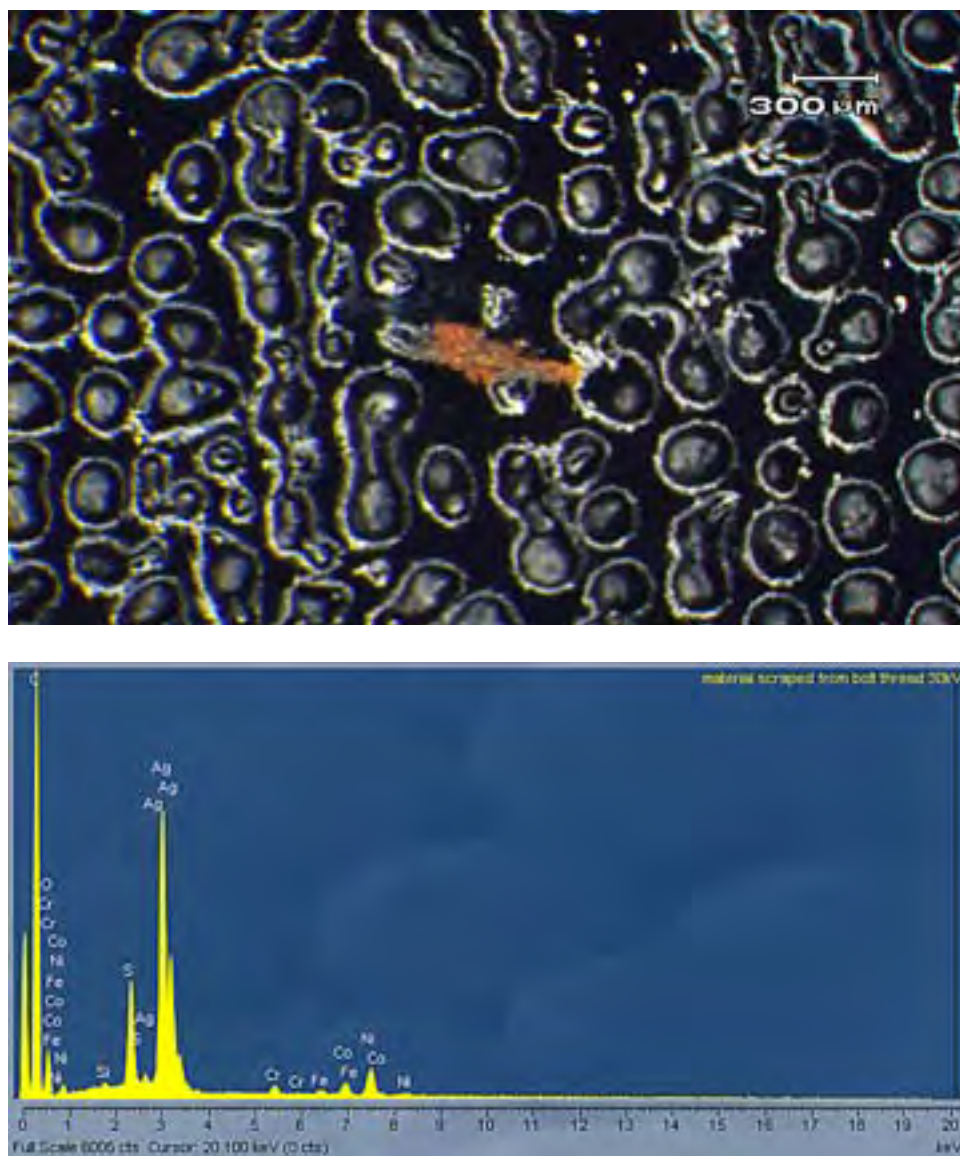


Figure 10. Material removed from the thread of a bolt after water washing placed on carbon tape for EDS analysis (top), EDS spectrum (bottom).

There are several possible explanations for the presence of silver and sulphur in a residue on the threaded sections of the turbine bolts.

1. Silver in the thread surface residue originated from the silver plating on the nut. There is no obvious mechanism for the deposition of silver on regions of the bolt other than those in intimate contact with the nut thread.

2. Silver, in a finely divided form was introduced into the threaded joint and the threaded end of the bolt as part of thread lubricant. It is a requirement that a thread lubricant be applied to the bolt threads during assembly. [The instructions for installation of HP turbine disk contained within Pratt & Whitney Canada Overhaul Manual, part number 3034623, require that the turbine bolts be lubricated with engine oil prior to measuring the rundown torque and the application of the final assembly torque (rundown torque plus 250 to 260 lbf.in). Synthetic turbine oils, Aeroshell 500 and 555 contain Tricresyl Phosphate. No evidence of the element phosphorus was found during the energy dispersive X-ray analysis of the residue on the bolt threads].
3. Sulphur in the thread residue originated from sulphur compounds present in the compressor bleed air.
4. Sulphur was present in the material applied to the bolt threads during turbine assembly.

The turbine bolts were examined for the presence of material that may have penetrated the bolted joint during operation. A small deposit of dust was found in the head fillet and in the part numbers stamped into the bolt head. This material was analysed by energy dispersive X-Ray spectroscopy (EDS), see figure 11.



Figure 11(a). Extent of dust deposit in the bolt head fillet.

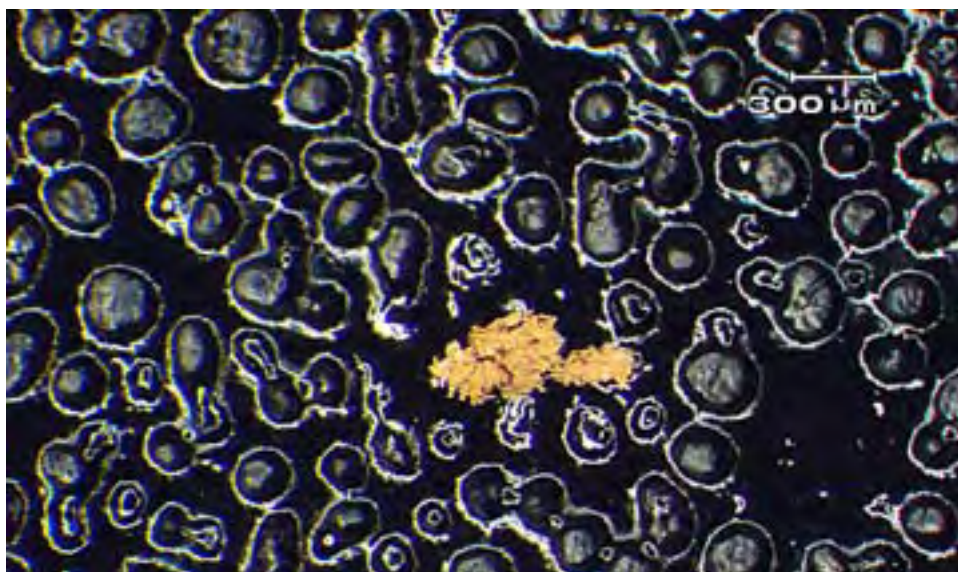


Figure 11(b). The appearance of the dust carefully scraped from a bolt head fillet

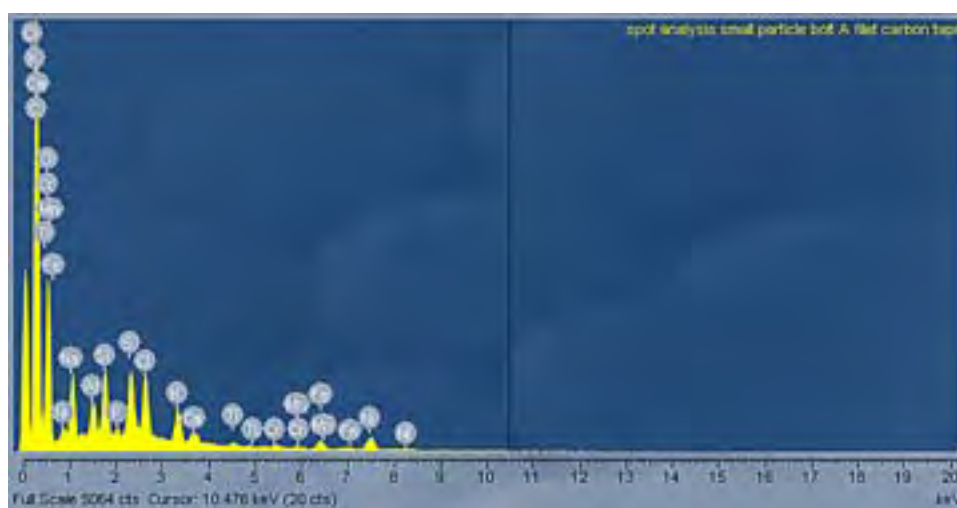


Figure 11(c). EDS analysis of dust removed from a bolt head fillet by stripping with carbon tape.

Sulphur is present in the dust deposit, probably as a sulphate, along with sodium and chlorine, probably as salt. These two compounds are common in maritime environments. The remaining elements are typical of various mineral oxides present in dust. The sample was taken from a bolt that had not been washed in water.

Examination of the bolt head fillet, where dust had been deposited, revealed that the presence of the dust deposit had not resulted in any abnormal oxidation of the bolt surface.

No dust deposits were found along any of the bolt shanks.

5. CONCLUSIONS

The failure of the bolts used in the assembly of the high-pressure turbine disk was caused by fatigue crack growth. Crack initiation occurred in the thread roots in the vicinity of the bearing face of the nuts.

It is apparent that the reaction of a compound or compounds based on the elements of silver and sulphur, caused the abnormal oxidation of the threaded sections of the bolts.

The nature of deposits on the threaded sections of the bolts is consistent with the application of a silver-based thread lubricant. This form of thread lubricant differs from the lubricant specified in the engine assembly procedures – turbine engine oil.

The origin of sulphur in the thread deposits could not be determined with certainty. There are two possibilities; sulphur was present in material applied to the threads, or the sulphur containing compounds in the compressor bleed air infiltrated the bolted joint and reacted with the thread lubricant.

6. SAFETY ACTION

In recognition of the adverse effect of applying thread lubricants that differ from those specified by the engine manufacturer, the engine service centre that assembled engine s/n 115120 has alerted workshop staff and clearly highlighted instructions in workpackages.

A handwritten signature in black ink, appearing to read 'Roueyn', is located below the safety action text.

24-3-2004