Australian Government

Department of Defence
Science and Technology

RTM322 Engine Bearing Red Substance Contamination and Corrosion Investigation

Paul Rawson, Andrew Becker, Jo-Anne Creek, Darren Gerrard and Cathy Smith

Aerospace Division
Defence Science and Technology Group

DST-Group-TR-3608

ABSTRACT

Defence Science and Technology (DST) were asked to investigate the nature and cause of a red gelatenous substance observed in the lubrication system of several RTM322 engines fitted to Australian Defence Force (ADF) MRH90 Taipan helicopters. The contaminant and associated corrosion had been responsible for the unscheduled removal of several engines from the ADF fleet in two tranches over a period of approximately 3 years. DST analysis revealed that a complex interaction was likely occurring involving an adverse chemical reaction between the synthetic MIL-PRF-23699 lubricant and a coating on bearings within the engine (likely a bearing preservative fluid).

RELEASE LIMITATION

Approved for public release.

Produced by

Aerospace Division
Defence Science and Technology Group
506 Lorimer Street
Fishermans Bend VIC 3207

Telephone: 1300 333 362

June 2019

APPROVED FOR PUBLIC RELEASE

RTM322 Engine Bearing Red Substance Contamination and Corrosion Investigation

Executive Summary

The Navy Aviation Systems Program Office (NASPO) requested DST analyse a red substance that had been identified around bearings in the lubrication system of several RTM322 engines. These engines are fitted to MRH90 helicopters, a sub-fleet of which are operated by the Royal Australian Navy (808 Squadron). Later investigation in consultation with Airbus Helicopters identified the same substance in several Australian Army MRH90 helicopters. DST identified the red substance as a metal quinizarate salt, which had been assessed as benign in a previous investigation involving unfiltered gearboxes on a different fleet of ADF helicopters. In the case of the RTM322 engines, however, the red substance was accompanied by significant localised corrosion around bearings in the vicinity of the red substance resulting in bearing degradation and ultimately premature engine removal.

DST analysis revealed that a complex interaction was likely occurring involving an adverse chemical reaction between the synthetic MIL-PRF-23699 lubricant and a coating on bearings within the engine (likely a bearing preservative fluid). Several other contributing factors were identified that may have accelerated the pace of bearing degradation such as water content and compressor wash detergent in the lubricant. The quinizarate is known to form around a metal species and in this case DST confirmed zinc and to a lesser extent copper were the metals causing the formation.

The contamination issue had been detected by metallic wear particles on magnetic chip detectors or prematurely blocked lubrication filters. The corrosion and subsequent metallic debris liberation had caused a significant portion of the engine fleet to be prematurely removed. Several aspects of this investigation are yet to be explained satisfactorily and evidence of the continued impact of the resulting corrosive substance is detailed.

This page is intentionally blank.

Authors

Paul Rawson
Aerospace Division

Paul Rawson graduated with a Degree in Applied Science from the University of South Australia in 1986. He began work at Mobil Port Stanvac Oil refinery in 1987 for two years before joining the then DSTO's Weapons Systems Division working in the propellants group. He joined the Fuels & Lubricants team in 1991. The duties in his current position include research and field problem solving for all aspects of aviation fuel and lubricants for ADF equipment including oil chemical condition monitoring.

Andrew Becker
Aerospace Division

Dr Becker joined the Royal Australian Navy in 1986 as a Sea King helicopter technician attached to 817 squadron. He was selected for degree studies and in 1993 graduated from RMIT University with a Bachelor of Mechanical Engineering degree. Dr Becker then served as a Marine Engineer primarily in the guided missile destroyer HMAS Brisbane completing several tours of South-East Asia. He joined the Defence Science and Technology Group in 1998 and has focused on condition monitoring of aviation propulsion systems, specialising in wear debris analysis. In 2007 he spent 18 months attached to Pratt & Whitney in Hartford working on the Joint Strike Fighter F135 engine program. Dr Becker holds a Masters and a PhD in the field of inductive wear debris sensors. In 2016 Dr Becker was awarded the Royal Aeronautical Society (Australian Division) Safety Award for work to improve the detection of wear debris in aircraft filters.

Jo-Anne Creek
Aerospace Division

Jo-Anne graduated from James Cook University with a Bachelor of Science degree in 2006 majoring in chemistry. Jo-Anne participated in an industry traineeship conducted at CSIRO Lucas Heights and also worked as an analytical chemist before joining DST in 2007. Jo-Anne worked in the Land Division Chemical Hazard Management Team investigating chemical warfare agent degradation processes and optimising analytical methods for Chemical Defence programs. She was then seconded to the Work Health Safety (WHS) Section as DST Corporate Hazardous Chemical Safety Advisor where she received a Defence commendation for her contributions to the Hazardous Chemicals Enforceable Undertaking Project, and then as WHS representative for DST Aerospace Division in 2016. Since 2017, she has been a key member of the Aerospace Metallic Technologies capability providing chemistry expertise in forensic incident investigations.

Darren Gerrard
Maritime Division

Darren Gerrard is currently a Science Team Leader on Navy & Army Aviation Corrosion Management in the Corrosion Science Group of DST Group's Maritime Division. He leads the Cold Spray Coating program (also known as Supersonic Particle Deposition) for the protection and repair of aerospace components. His task covers assessment of corrosion prone areas on the C-130 Hercules, P-3 Orion, F/A-18, S-70B-2 and MH-60R Seahawk, MRH90 Taipan and ARH Tiger aircraft; investigation of hydrogen embrittlement of high strength steel structures from metal coating processes, aerospace cleaning materials, environmental embrittlement and other processes. It also includes investigation and assessment of alternative coatings including hard chromium and cadmium plating replacements. Darren holds a Bachelor of Applied Science in Applied Chemistry from the Royal Melbourne Institute of Technology (RMIT) (1981), a Graduate Diploma in Metal Finishing and Surface Protection from RMIT (1987) and awarded the Taubmans Prize for Top Student in Metal Finishing II, and a Master of Engineering Science in Materials Engineering from Monash University (2002). Darren has also completed the Graduate Certificate in Scientific Leadership from Melbourne University (2007).

Cathy Smith
Aerospace Division

Cathy graduated from Monash University, Melbourne in 2004 having obtained a Bachelor of Engineering (Materials) with first class honours. Following five years at Rio Tinto as a Research Engineer specialising in aluminium products, Cathy joined DST in 2010 within the area of Aircraft Forensic Engineering and Accident Investigation. Since then Cathy has been involved in numerous investigations of ADF aircraft component and systems failures, including engine failures and accident investigation. Cathy is currently a senior aerospace forensic scientist and researcher.

Contents

This page is intentionally blank.

1. Introduction

In early 2015 DST Group were asked by the Navy Aviation Systems Program Office (NASPO) to investigate the source of a tenacious red substance that was observed in the engine lubrication filters of several Royal Australian Navy (RAN) MRH90 Taipan helicopters. During this initial period 12 RTM322 engines from the ADF fleet were the subject of unscheduled removal due to this issue. The subject engines were removed due to metallic wear debris captured on magnetic chip detectors that also showed an unusual red solid with a gelatinous appearance. During engine overhaul the bearings were observed to have a coating of a tenacious red substance (later identified as quinizarate) that coincided with extensive corrosion of bearings.

Although the management of this aircraft resides predominantly with the Australian Army, the RAN operate a sub-fleet. The observation of the red substance initially appeared to be confined to RAN MRH90 helicopters, however it was later detected in several Australian Army MRH90 helicopters. According to the OEM (Airbus Helicopters) the substance had not been previously reported in any other international fleet. Whilst DST had observed and analysed a similar red substance in other ADF fleets [1], it had been assessed as benign and had not been associated with deterioration of internal lubricated engine components.

Despite a significant combined effort on the part of DST and Airbus Helicopters to identify the source and effect of the red substance related to the 2015 engine removals, DST consider that the root cause was never satisfactorily explained. Several changes were made to the operation of the engines and the unscheduled removals appeared to subside. A final report published by Airbus Helicopters in 2016 [2] identified high water content resulting from incorrect compressor washing technique as the primary root cause. DST does not accept this as the primary root cause as it was not consistent with key observations of the affected engines.

In 2018 this issue re-emerged and resulted in at least seven additional unscheduled engine removals from four different aircraft in the ADF fleet. A Special Technical Instruction (STI) was subsequently issued on 16 October 2018 [3] to inspect magnetic chip detectors and oil filter elements for the presence of the red substance. DST provided support for this STI by analysing debris captured on the magnetic chip detectors and extracted from filter elements.

This report describes the DST contribution to the investigation and provides a plausible primary cause consistent with the observed evidence.

2. RTM322 Engine

The MRH90 is powered by two RTM322 turbo-shaft engines (Figure 1) manufactured and supported by Safran Helicopter Engines (Safran HE). Each engine produces approximately 1662 kW and has a self-contained filtered lubrication system (Figure 2) feeding the main shaft bearings via two primary circuits (Front and Rear) as well as accessory drive gears and bearings. The scavenge oil system contains a single indicating magnetic chip detector and two non-indicating magnetic chip collectors with screens used to determine which group of bearings is producing abnormal wear debris. The engine contains bearings from at least three different manufacturers: SNFA, FAG (now Schaeffler) and SKF. According to a partial metal map currently available for this engine, the bearings are made of either 100Cr6 or E80DCV40 low alloy bearing steels depending on the specific location.

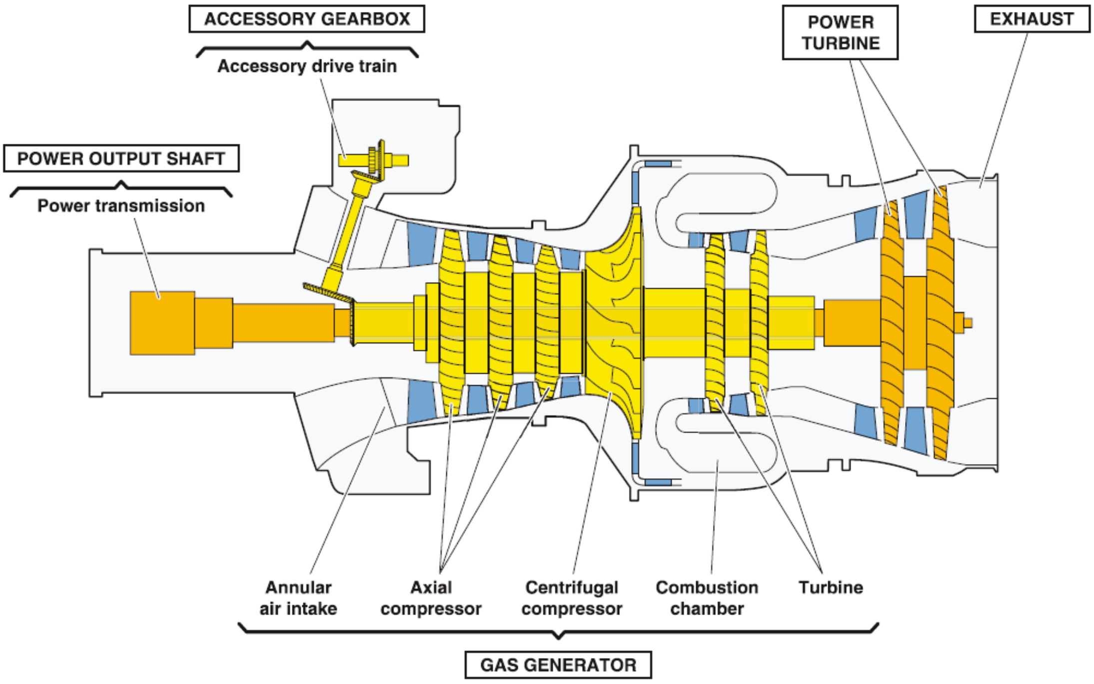


Figure 1: Schematic of RTM322 engine [4]

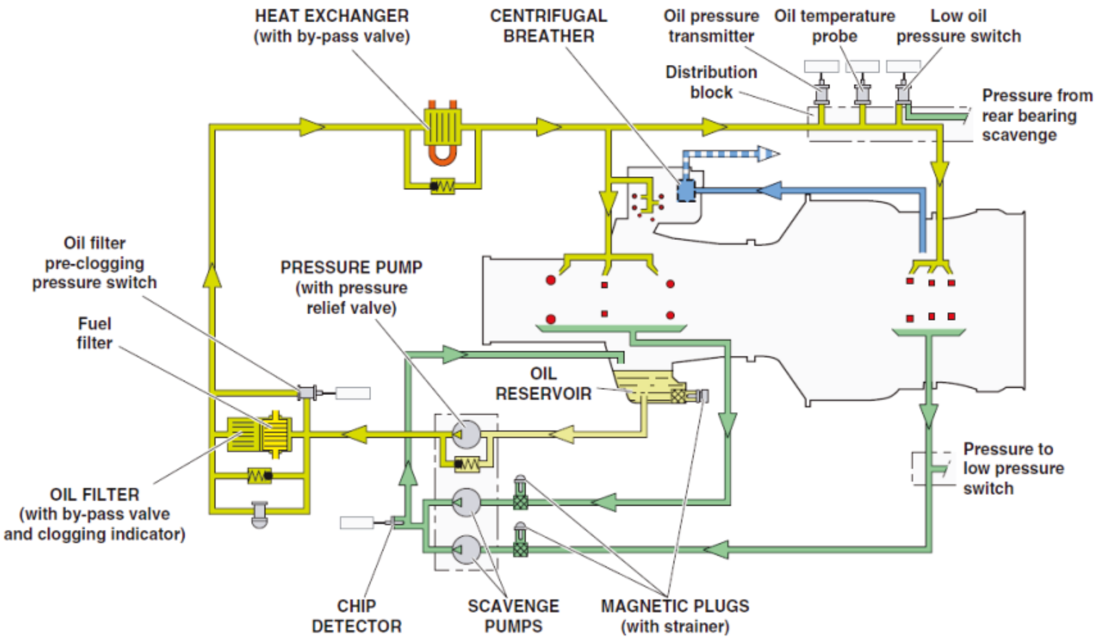


Figure 2: RTM322 lubrication system schematic [4]

3. Red Substance Investigation

Initially, the red substance was observed in 2015 by maintenance staff in the process of changing filter elements that had bypassed due to high differential pressure. The substance was also observed coated on metallic debris captured by magnetic chip detectors. The substance was subsequently associated with localised corrosion on some engine bearings (Figures 3 to 5). In some cases the corrosion had resulted in metallic debris being liberated from bearings, which ultimately resulted in engines being prematurely removed for repair.

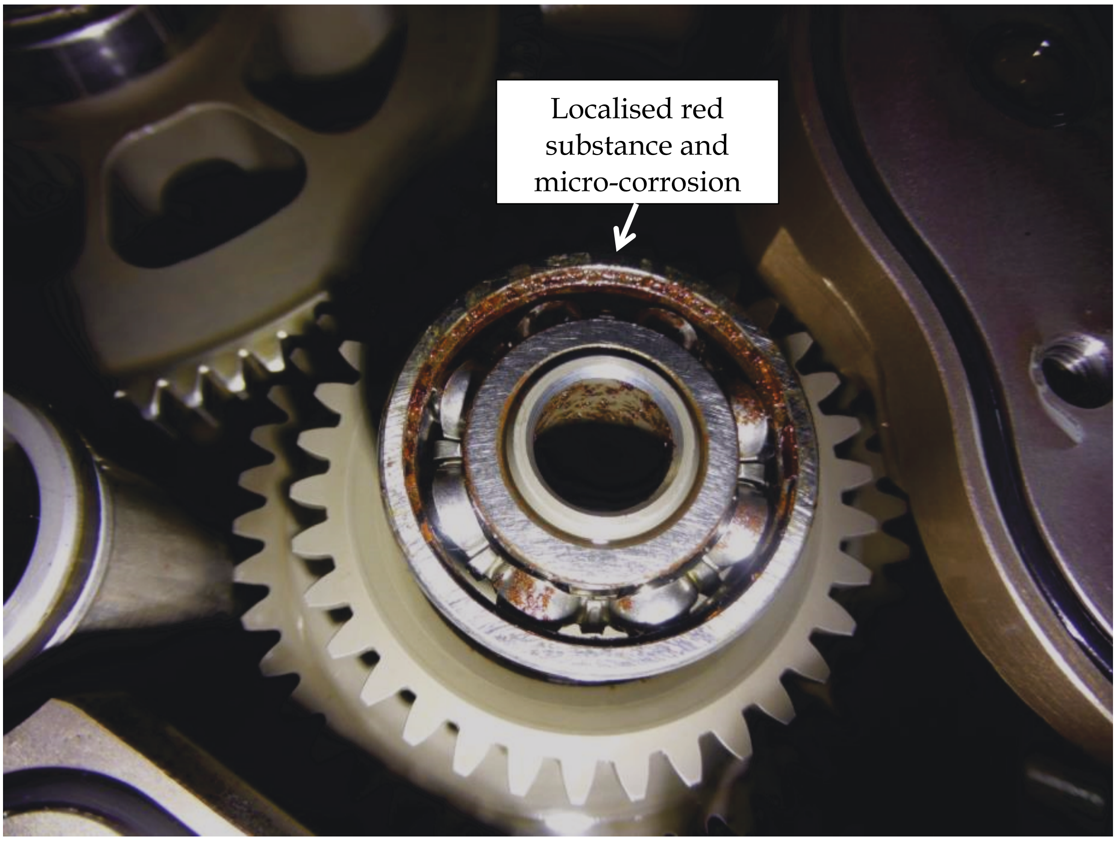


Figure 3: RTM322 accessory gearbox bearing showing the localised nature of the quinizarate and associated corrosion (Image courtesy of Safran HE)

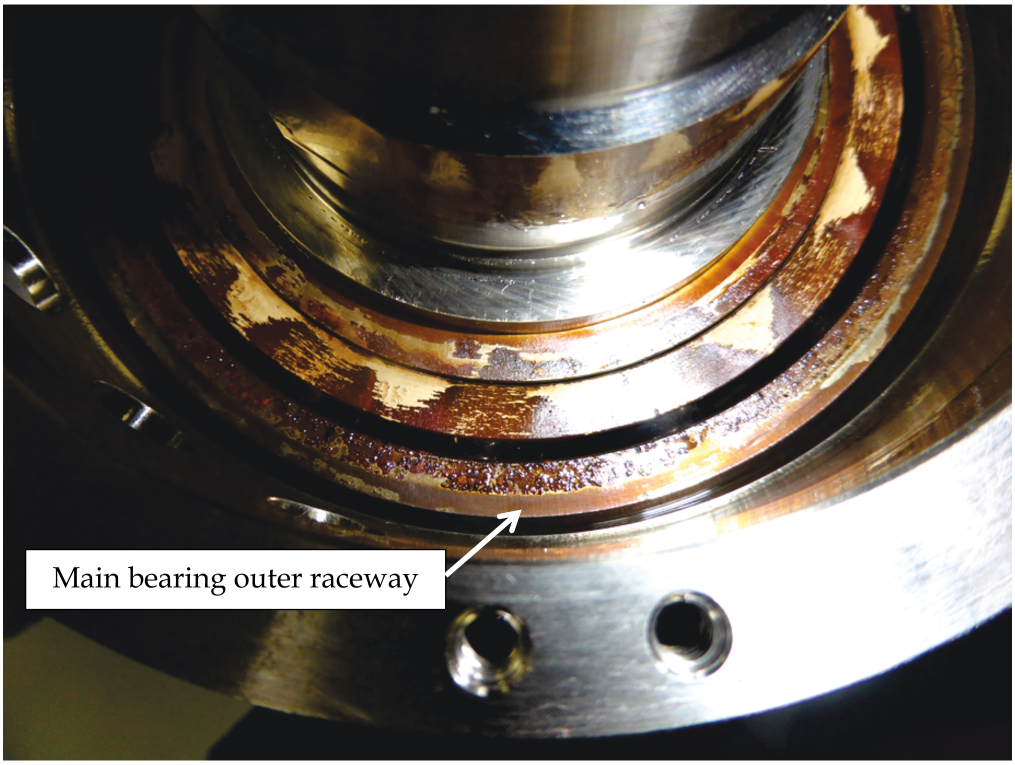


Figure 4: RTM322 main bearing showing localised quinizarate and corrosion (image courtesy Safran HE)

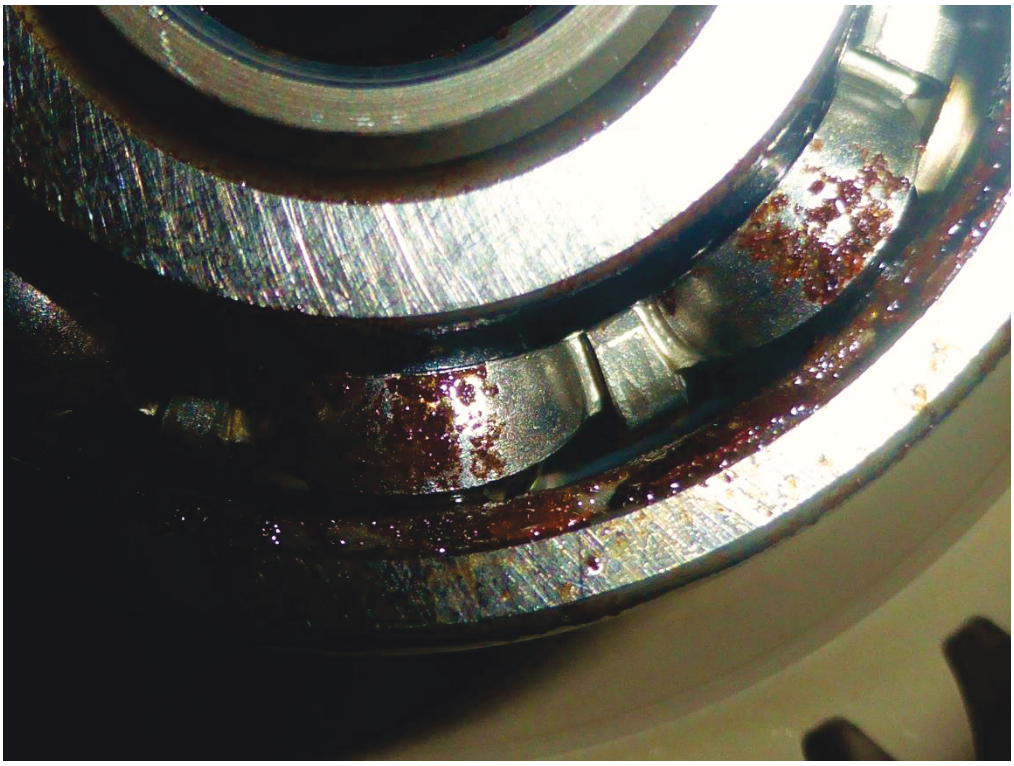


Figure 5: Image of bearing showing red substance on bearing cage and raceways (image courtesy of Safran HE)

3.1 Red Substance Characteristics

Early in the investigation DST observed that the red substance and associated corrosion regions were exclusively located around rolling element bearings (Figures 3 to 5), although some of the substance had been transported to the filter and magnetic chip detector via the scavenge system. Being localised exclusively to bearings was considered unusual and not consistent with a bulk lubricant contamination issue. A bulk lubricant contamination issue (e.g. high Total Acid Number or high water content) would be expected to affect most low alloy steel components in the lubricated system. Gear, shaft and bearing steels are classified as low alloy steels and have similarly poor corrosion resisting properties due primarily to the relatively low chromium (Cr) content. As can be seen in Figures 3 to 5, the nearby components (e.g. gears, shafts, casing etc.) were pristine and showed no evidence of the red substance or corrosion despite being in the immediate vicinity and exposed to the same lubricant. The localised nature of the red substance and corrosion was a fundamental observation that DST considered critical for determining the likely primary cause.

3.1.1 Chemical Analysis of Red Substance

DST analysis of the red substance identified it as being a quinizarate salt based on zinc (Zn) and to a lesser extent copper (Cu). The quinizarate originates from quinizarin that has reacted with metal ions in the lubricant to form the metal salt. Quinizarin is an additive in synthetic lubricants typically used as a metal passivator and belongs to the family of chelating agents that actively reduce the catalytic activity of metal ions. Of the four commonly used MIL-PRF-23699 aviation lubricants in the ADF, two use quinizarin as the passivator (Table 1). The additive works by reacting with a reactive metal ion and forms a stable and non-reactive chelate. If reactive metal ions are not passivated in this way then they can catalyse oxidation of the lubricant thus reducing its useful life. The additive is present typically in the range of 0.1- 0.5% w/w, however the exact concentrations varies in the different brands of MIL-PRF-23699 used in the ADF.

Table 1: Common MIL-PRF-23699 Lubricants used in the ADF

Lubricant	Base Lubricant Colour	Metal Passivator
Mobil Jet Oil II	Orange	Quinizarin
BP Turbo Oil 2380	Clear	Benzotriazole
NYCO Turbonycoil 600	Orange	Quinizarin, Benzotriazole
Aeroshell 500	Light Orange	Unknown (No Quinizarin)

Analysis of the red substance confirmed it was mixture of quinizarate, the derivative salt from quinizarin (1,4-dihydroxyanthraquinone) reacting with metal ions and a range of carboxylate salts. DST analysis suggested that the bulk substance was made up of carboxylate salts which have a gel-like appearance, with the red colour resulting from the lower concentration quinzarate salt. The red substance was examined in detail and found to be made up of salts of the following acidic compounds:

1. Pentanoic, heptanoic and ocantoic acids which are sourced from the acids used to make the base polyol ester of the MIL-PRF-23699 oil.
2. Decanedioic, undecanedioic and dodecanedioic acid salts. These were found in both ZOK27 and ARDROX 6367 compressor wash solutions with decanedioic acid salt being the most abundant. They form part of the anti-corrosion additive package of the wash solutions.
3. An alkyl ethanolamide detergent found in both ZOK27 and ARDROX 6367.

Formation of the red quinzarate salt requires the metal to be dissolved into its ionic form and to react with the quinizarin; this may be caused by dissolution into water in the oil or via reaction with weak organic acids. Polyol ester oils are made from weak organic acids and hydrolysis and production carry over from incompletely reacted base oil material may initiate the dissolution of these metal ions making them available to react to form the resultant coloured substance. Different metal ions will tend to form different coloured salts.

The combination of quinizarate and carboxylate salts (and possibly water content in some cases) appears to have resulted in a highly corrosive micro-environment localised around the bearings. This is likely to have been a result of an adverse reaction between the lubricant and a coating that existed only on the bearings, probably post-manufacture and pre-installation. Once the corrosion commenced, it progressed until metallic debris was liberated and detected by the magnetic chip detector. Once debris limits had been exceeded, in most cases the engine was removed for unscheduled overhaul at significant cost.

3.1.2 Scanning Electron Microscope Analysis

Further analysis of the composition of the red substance using a Scanning Electron Microscope (SEM) with Energy Dispersive Spectroscopy (EDS) identified zinc (Zn) and to a lesser extent copper (Cu) and calcium (Ca) present in all samples (Figures 6 and 7). Zinc (Zn) and copper (Cu) are not part of the additive package for any of the MIL-PRF-23699 lubricants nor are they present in the compressor wash solutions used by the ADF. These elements are, however, known to be present (with silver (Ag)) in the engine labyrinth seal brazing alloy used in this engine. The absence of silver (Ag) from the quinizarate analysis has not yet been able to be explained.

Figure 6 shows a typical analysis of the red substance on a bearing surface and shows the underlying bearing steel composition along with the presence of zinc (Zn), copper (Cu) and calcium (Ca). The bearing steel in this case was E80DCV40 which is a European equivalent to AISI M50 bearing steel commonly used in aviation propulsion systems, particularly in the hotter parts of a gas turbine. This alloy does not contain any zinc or copper. Figure 7 shows an analysis of the red substance in isolation as recovered from one of the bearings analysed.

Previous occurrences of quinizarate formation have been reported by DST [1], but were restricted to unfiltered gearboxes (e.g. helicopter Tail Rotor Gearboxes). DST could find no reports of quinizarate appearing in ADF engine lubrication systems prior to this occurrence. All previous occurrences in gearboxes were assessed as benign and were not accompanied by corrosion or debris generated from corrosion sites.

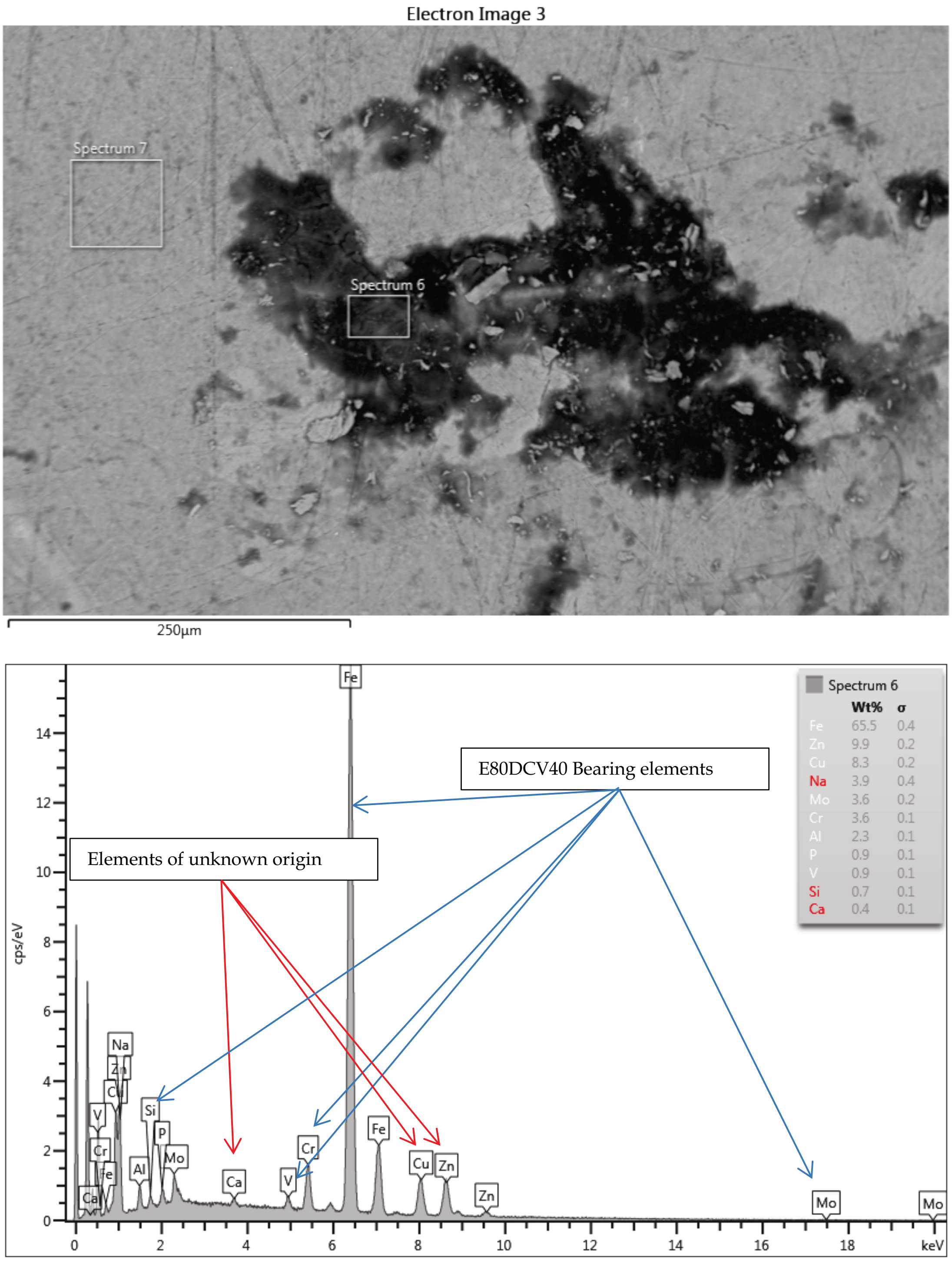


Figure 6: SEM EDS analysis of red substance residue on bearing surface

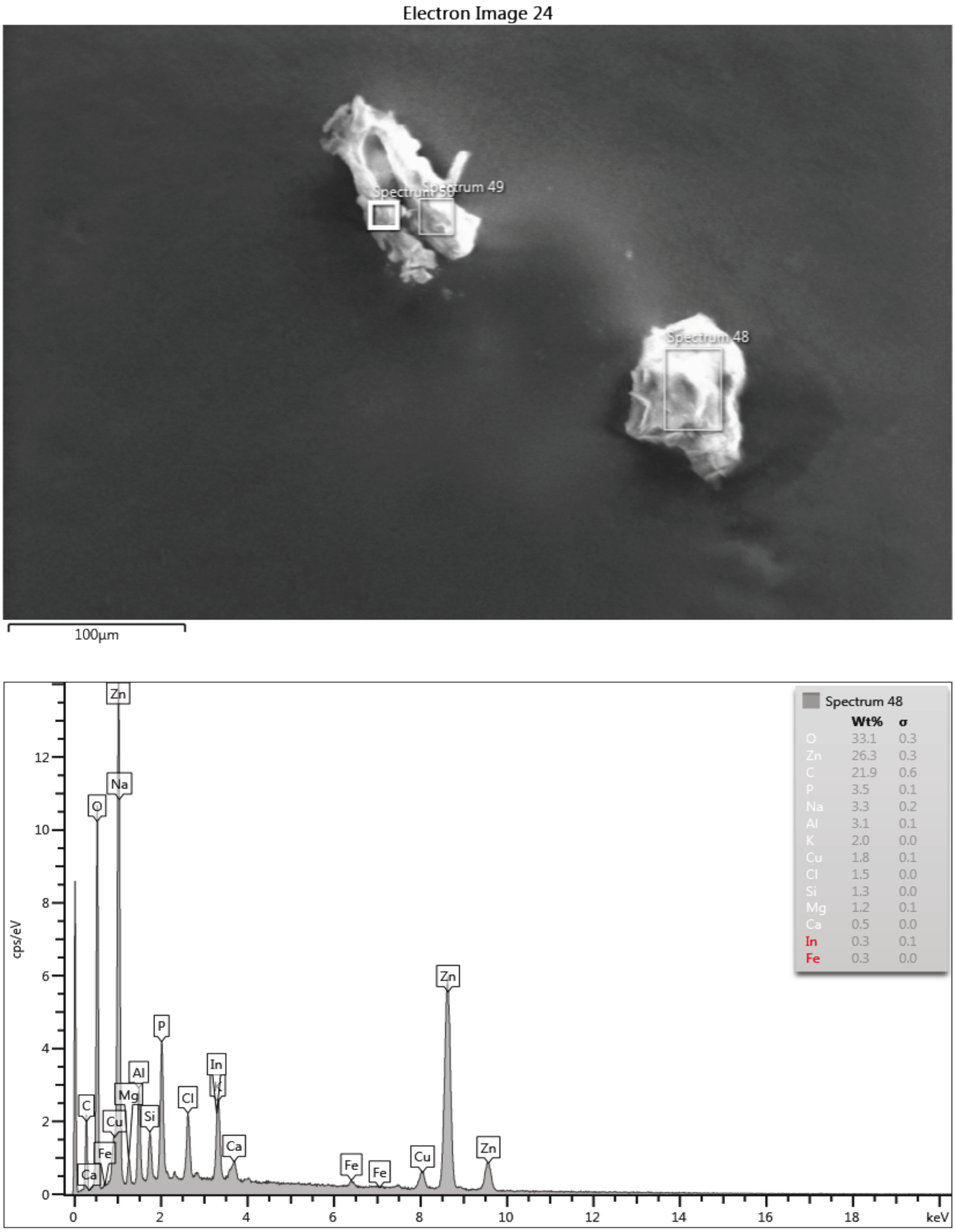


Figure 7: SEM EDS analysis of red substance from A40-016

3.2 Filter Debris Analysis

The analysis of filter debris can provide a high fidelity insight into the condition of the engine and lubrication system as they concentrate the solid particulate. DST conducts filter debris analysis in accordance with ASTM 7898-14 [5] and typically uses isopropyl alcohol as the solvent when working with MIL-PRF-23699 lubricants. During this investigation several filters were analysed to determine what had caused the filters to bypass and to extract evidence of the primary cause. Filters were also used as a visual confirmation check for aircraft that showed signs of red substance on magnetic chip detectors. Figure 8 shows an example of the red substance adhered to the outer aluminium alloy (6000 series or similar) mesh of a RTM322 lubrication filter element. Figure 9 shows an example of the extracted debris from engine serial number 6534; this was particularly unusual in having gross aluminium oxide particulate that was coated in the red quinizarate. A more typical filter extraction is shown in Figure 10. This image shows some quinizarate, however the bulk particulate is a light brown colour solid later identified as carboxylate salt.

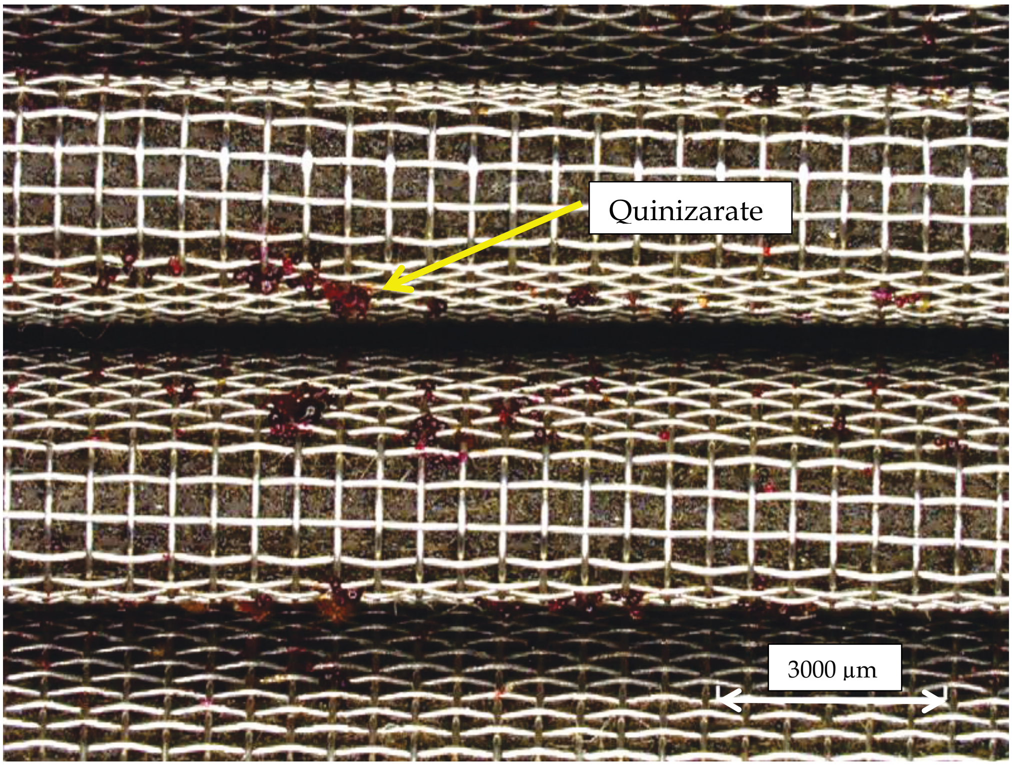


Figure 8: A40-011 filter showing red quinizarate attached to the filter mesh.

Figure 9: Filter debris extracted from A40-011 ESN 6534 showing extensive Al_2O_3 coated in quinizarate

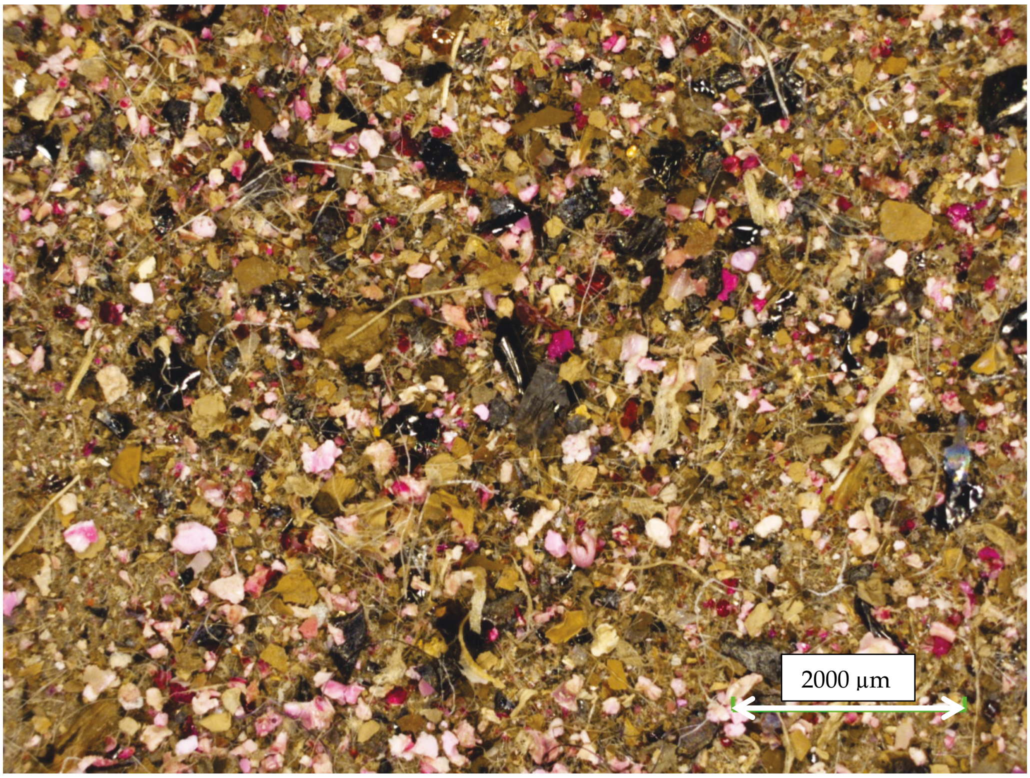


Figure 10: Filter extract from Engine 6500 showing some quinizarate

3.2.1 Filter cage mesh structural integrity loss

During the analysis of filter debris from one of the affected engines it was noticed that the outer aluminium alloy wire mesh (6000 series or similar) of the filter element had deteriorated and lost its structural integrity. It was observed that simply touching the mesh caused fracture of the wire strands. This observation was unusual and was not observed in all processed RTM322 filters. Figure 11 shows a comparison of two used filter elements following the extraction process. Filter (a) exhibited no structural integrity loss of the mess (typical) while the degradation of the mesh in filter (b) is evident. The filter extraction process does not cause damage to the filter mesh and DST had not observed this type of deterioration in any previous aircraft lubrication filter analyses. Figures 12 and 13 show magnified views of the filter mesh from the filters shown in Figure 11. Note in Figure 12 that quinizarate persists in the filter near the mesh junctions element even after the extraction process.

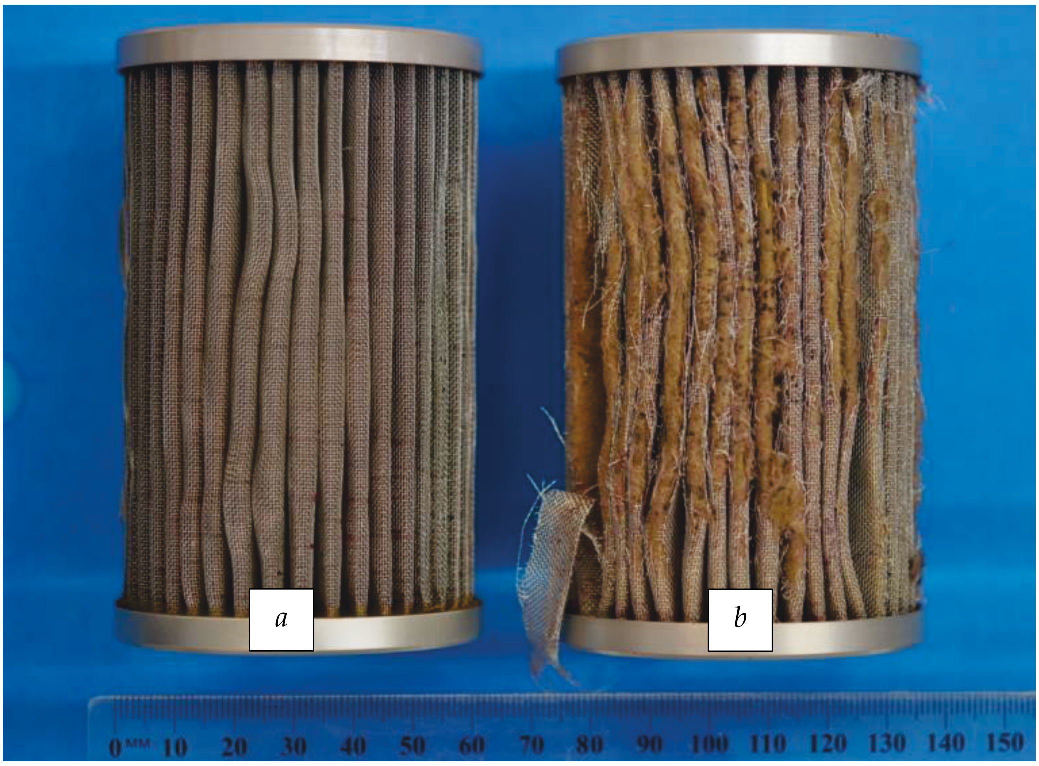


Figure 11: Comparison of used RTM322 filter elements following filter debris extraction process.

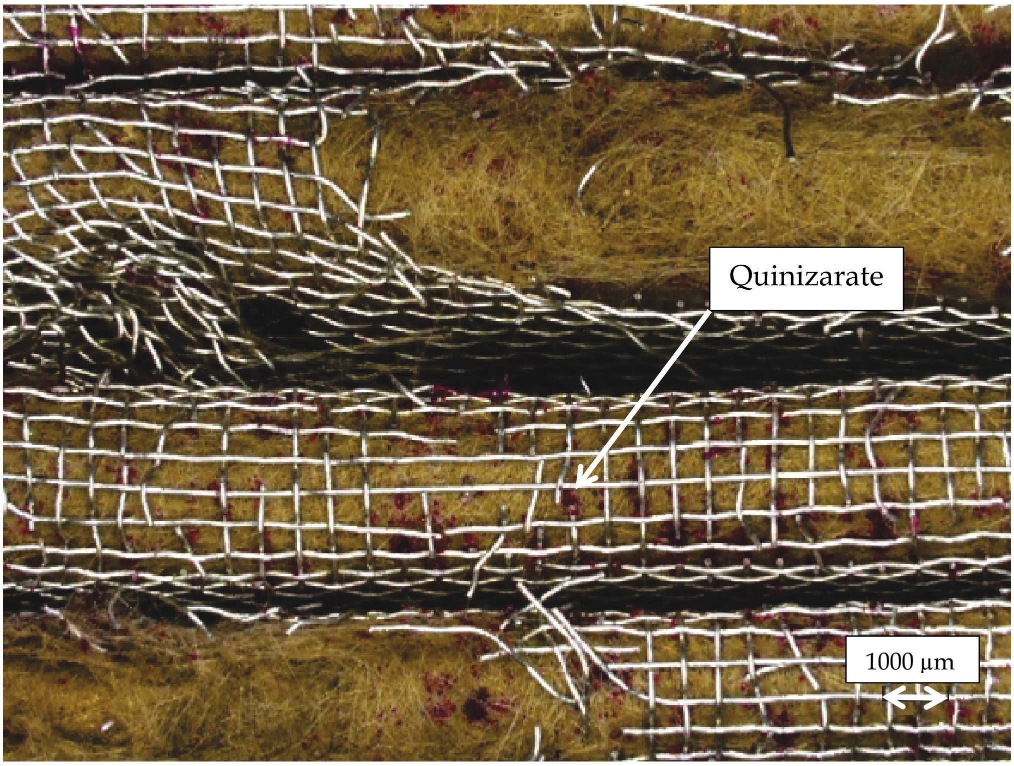


Figure 12: Close up of used RTM322 lubrication filter element (b) from Figure 11 showing the abnormal failed mesh and persistent quinizarate following cleaning.

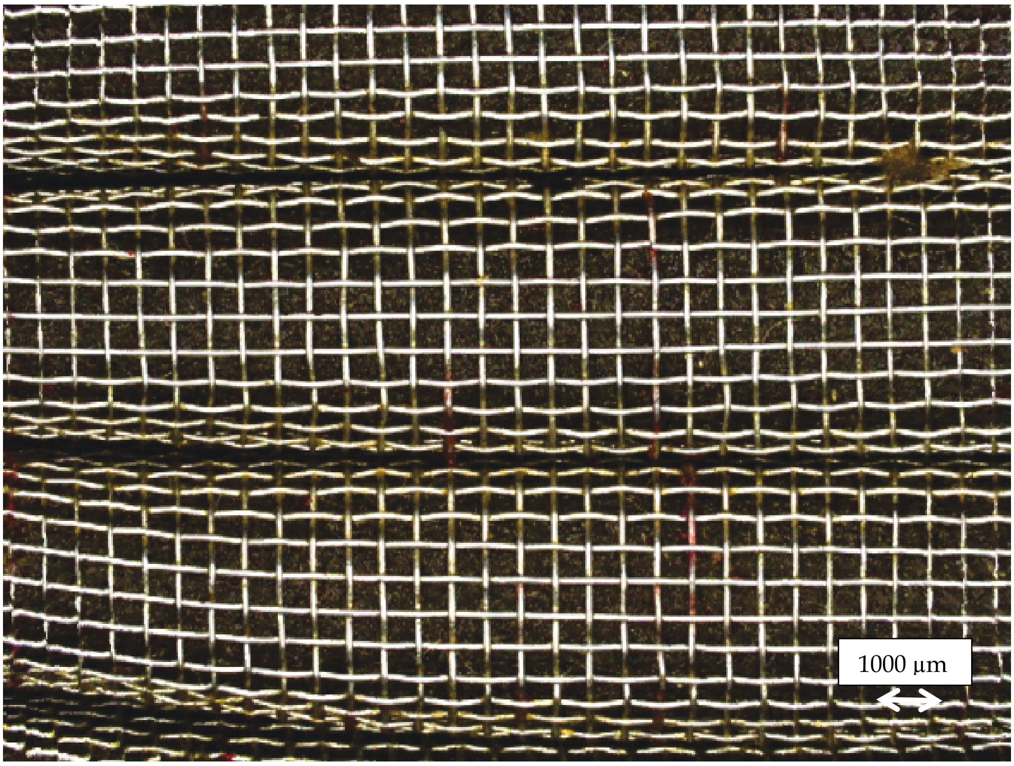


Figure 13: Close up of used RTM322 lubrication filter element (a) from Figure 11 showing mesh intact and appearing as expected.

Microscopic examination of the filter mesh strands revealed both the red substance (quinizarate) and another tenacious brown-coloured substance (Figure 14). The brown coloured substance was subsequently identified as a carboxylate salt.

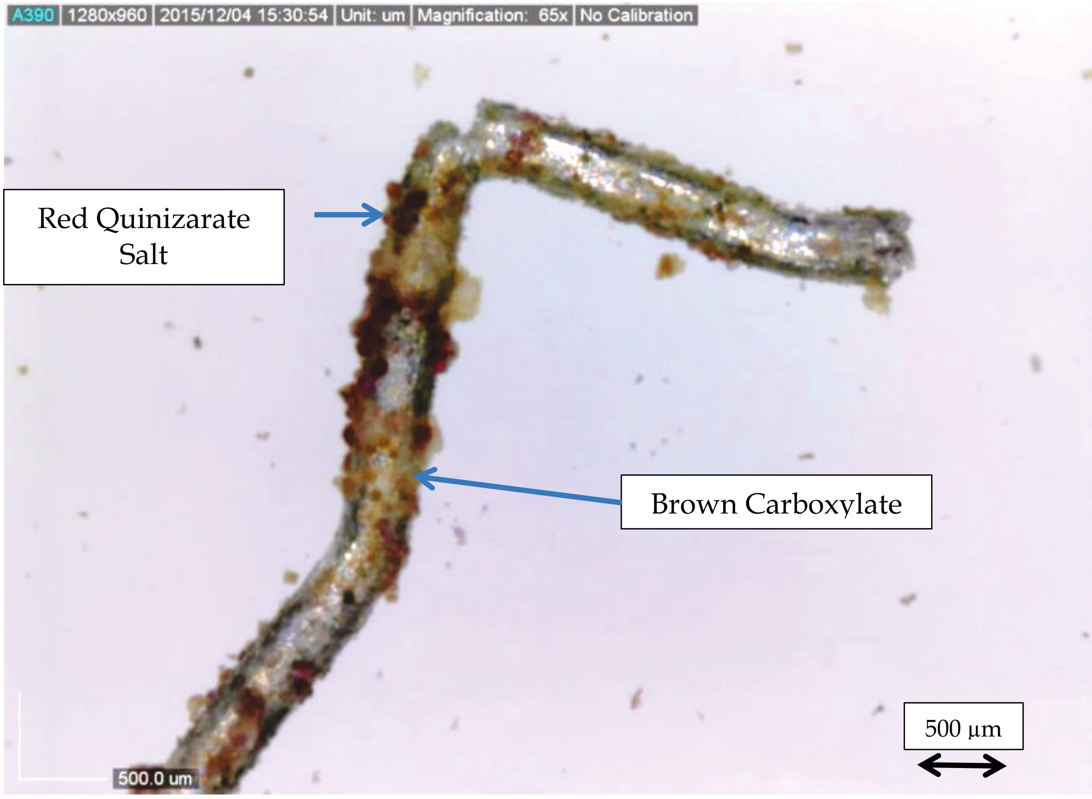


Figure 14: Example of a failed strand of the filter mesh from the degraded filter element showing tenacious brown substance (carboxylate salt) and red substance (quinizarate).

A sample of the wire mesh was further analysed and the fracture surface was assessed as being consistent with intergranular corrosion. Figures 15 and 16 show SEM images of the fracture surface and a strand that has partially broken. This aspect of the investigation caused some concern as it was realised that the attack on the aluminium alloy would not be exclusive to the filter element mesh and may attack other components in this critical system. DST concerns regarding this were passed to Airbus Helicopters and were reportedly noted on the aircraft risk register (See also Section 4.1).

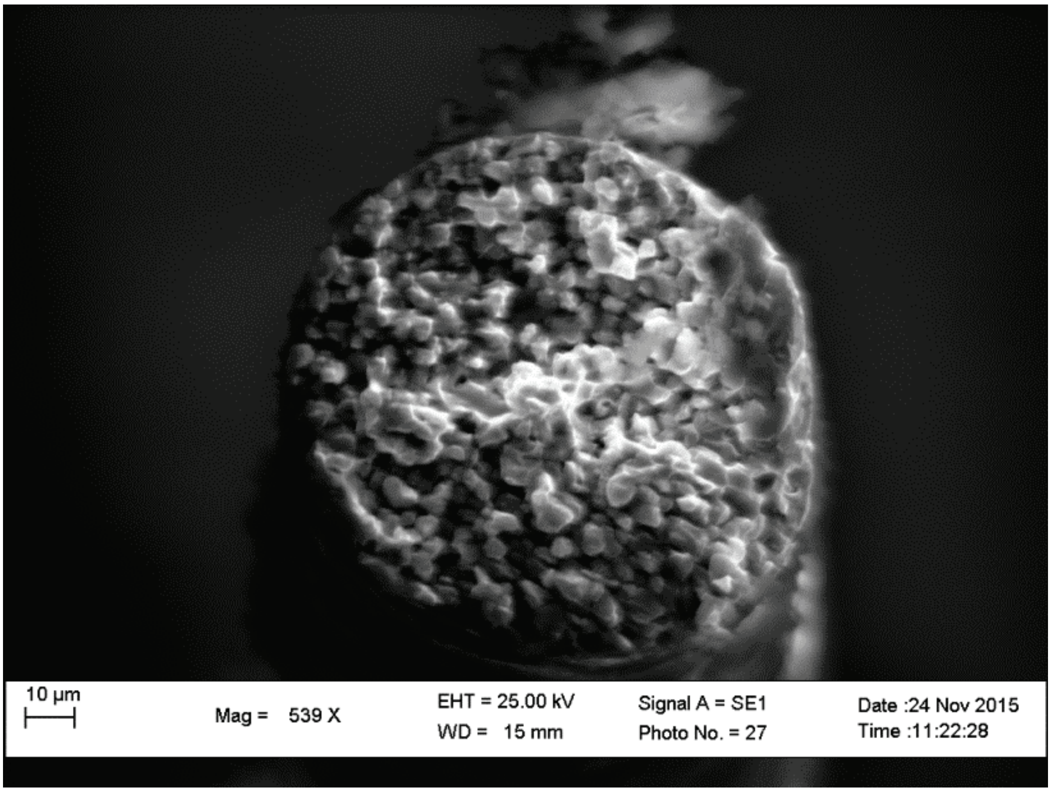


Figure 15: Fracture surface of a wire strand from the filter element outer mesh.

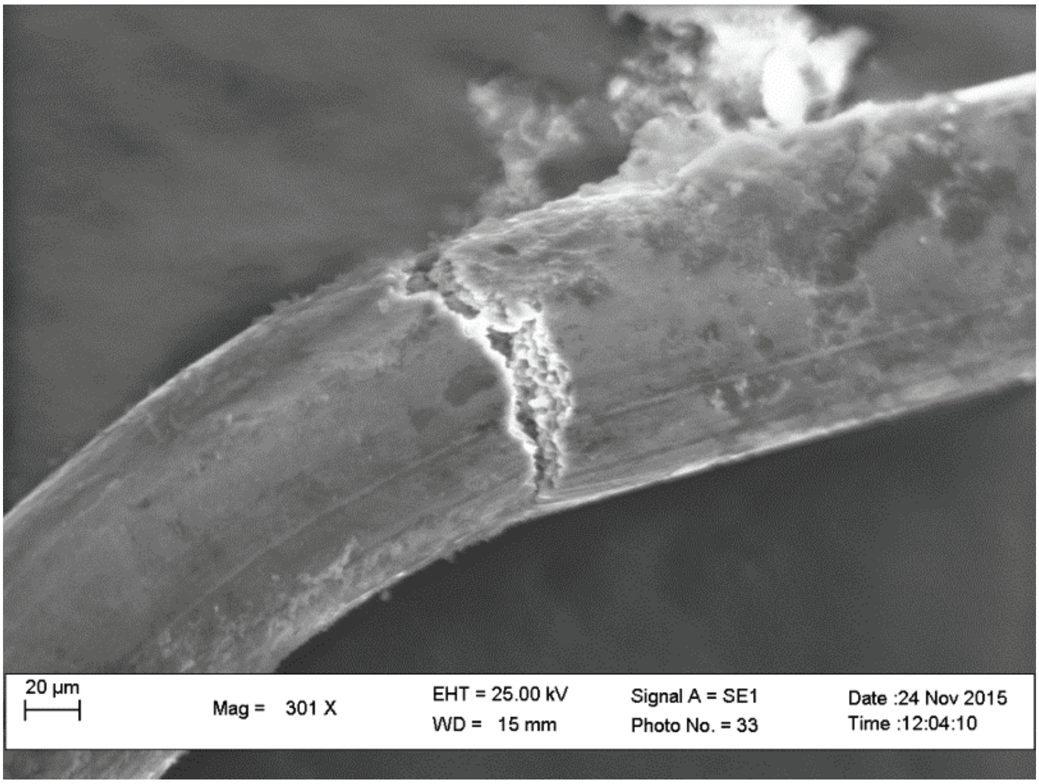


Figure 16: SEM image of filter element wire mesh strand that has partially broken.

3.3 Oil Analysis

Routine oil analysis consisting of spectrometric oil analysis, viscosity, Total Acid Number (TAN), and water content was not mandated by the OEM for this aircraft when it entered service. Following the initial identification of quinizarate and the associated corrosion, DST Group recommended the introduction of an oil analysis program to determine if any abnormal condition could be identified. One early theory thought to explain the corrosion was that incorrect compressor washing technique had resulted in high water content (with the associated compressor washing compound) in the lubricant resulting in corrosion. Whilst this may have been a contributory factor in some cases, it did not fully explain the highly localised nature of the corrosion, with adjacent gears and shafts showing no signs of corrosion.

To test if water content was an issue, Airbus Helicopters arranged for oil samples to be taken and tested by Intertek as part of a Special Technical Instruction. DST provided recommended in-service limits for MIL-PRF-23699 lubricants (Table 2) that had previously been developed for this type of lubricant. The results of the oil analysis showed that only a small number of engines had elevated water content. The experience in other ADF platforms has been that water content is rarely an issue in aircraft that are regularly operating. The typical lubricant operating temperature of around 90+°C is usually sufficient to drive off the majority of water from the lubricant and keep the bulk concentration well below the in-service limit.

Table 2: DST recommended in-service lubricant health limits for MIL-PRF-23699 lubricants

Test		**Recommended MIL-PRF-23699 lubricating oil in-service limits**	
		Warning Value	Interpretation
Viscosity (cSt @ 40°C)	Lower limit	**20**	Fluid must be maintained between 20 to 30 cSt.
	Upper limit	**30**	
TAN (mgKOH/g)		**2**	Fluid is serviceable if less than this value
Water content (ppm)		**1500**	Fluid is serviceable if less than this value

The primary lubricant condition results from the initial tranche of engines affected are shown in Figures 17, 18 and 19. Figure 17 contains a plot of water content (Karl Fischer method). What is clear from this plot is that only one aircraft had an abnormally high water contamination issue (A40-011), one was marginal (A40-015) and two others (A40-028 and A40-032) were considered slightly elevated based on experience with other Navy aircraft using the same lubricant. Only the samples for A40-011 would be considered unserviceable based on the extant fluid health limits. If compressor washing techniques were the primary root cause then all affected aircraft would be expected to show high water or TAN readings.

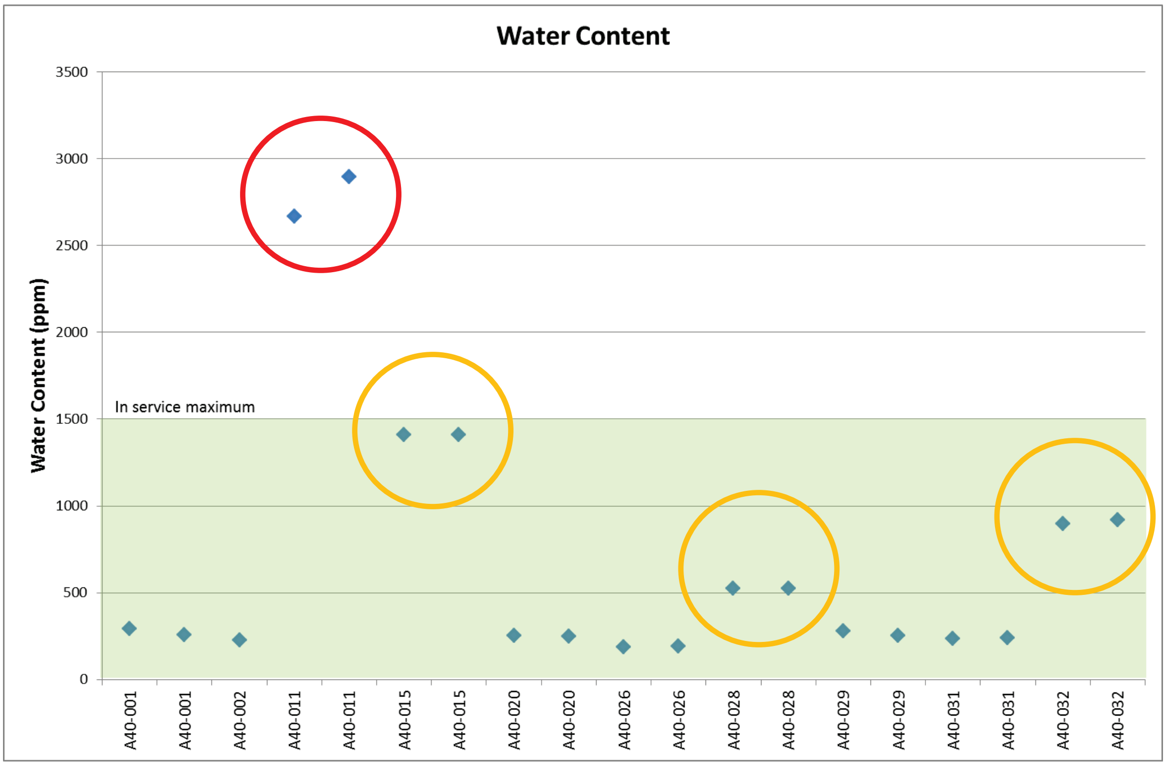


Figure 17: Plot of Water Content for MRH90 aircraft. Unserviceable results are circled red, marginal and slightly elevated results are circled yellow.

Figure 18 shows the Total Acid Number (TAN) readings for the same group of aircraft. TAN is a measure of the acidity of the lubricant and indicates the propensity of the bulk lubricant to cause corrosion in the system. For polyol ester lubricants such as MIL-PRF-23699, the presence of water can cause the lubricant to revert to its constituent acid and alcohol by the reversible equation (see Figure 20). The TAN results show no significant issue with the acidity of the bulk fluid. This is important to note as the corrosive nature of the bulk fluid had been considered as a possible cause of the internal localised corrosion.

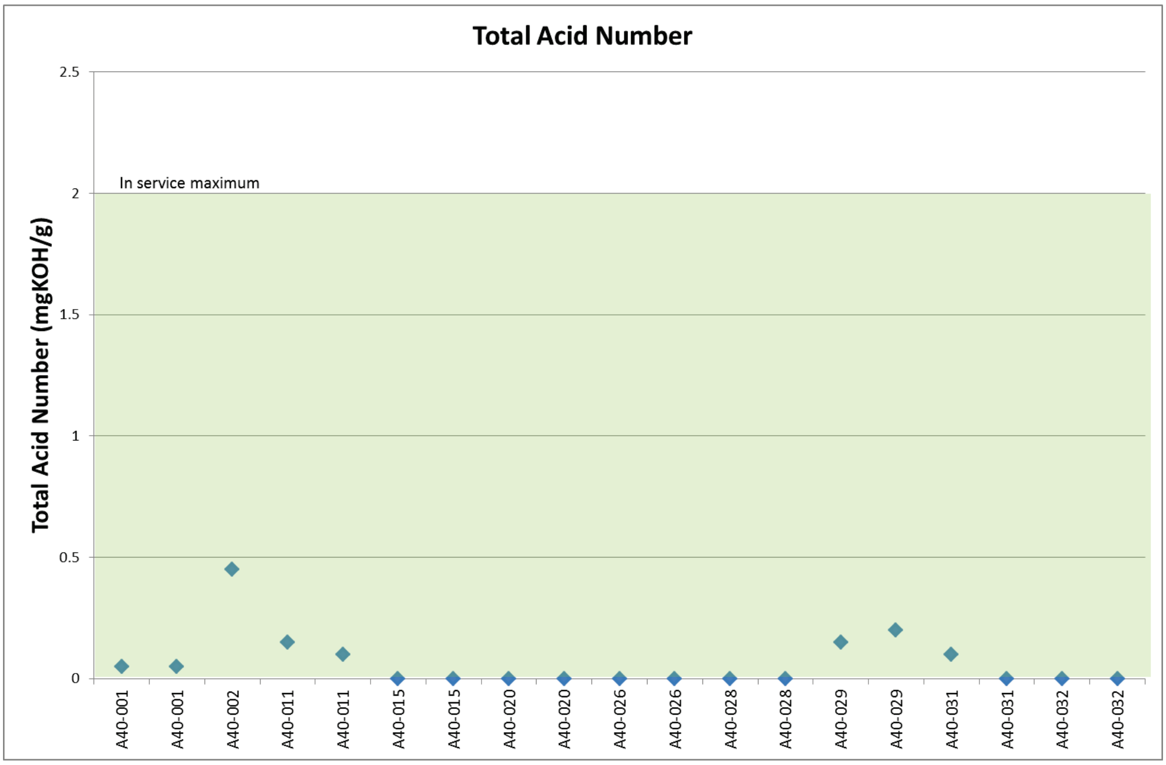


Figure 18: Plot of Total Acid Number (TAN) for MRH90 aircraft

Figure 19 shows the viscosity results with the recommended in-service band limit (i.e. upper and lower limit) overlaid. It can be seen from this plot that there were no significant issues with the viscosity in any of the aircraft tested, however the low viscosity measured for the two samples taken from aircraft A40-011 did coincide with extreme water content readings (see Figure 17). Viscosity is the most important parameter for lubricants and directly relates to machinery health and longevity, however it does not impact the corrosion propensity of the lubricant.

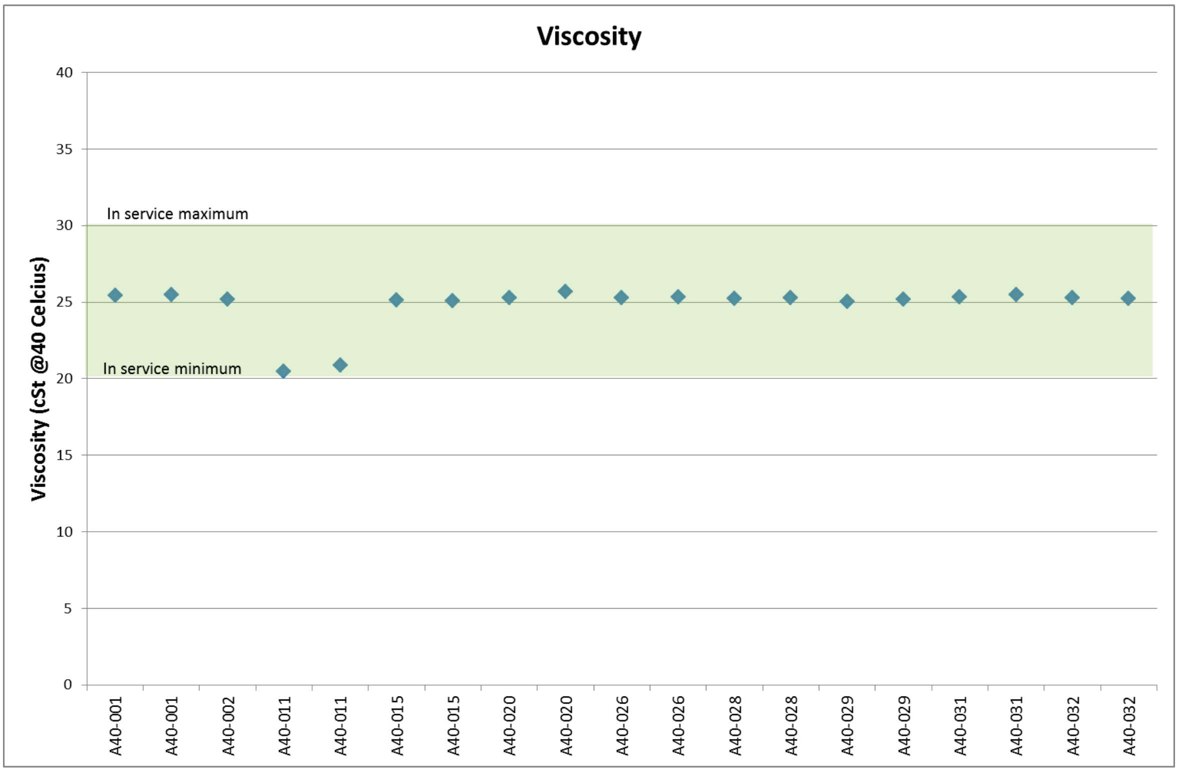


Figure 19: Plot of viscosity results for MRH90 aircraft

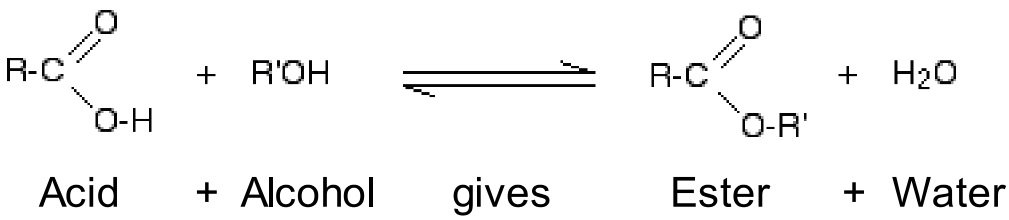


Figure 20: Fundamental reversible reaction that creates synthetic ester lubricants

Figure 21 shows the elemental concentrations for selected elements using spectrometric oil analysis (SOA). This technique detects particles up to approximately 8 microns in a liquid sample. In-service limits for SOA are typically system specific and in this case no authoritative limits were found to be published for the RTM322 lubrication system.

The results in Figure 21 clearly show that copper (Cu), zinc (Zn) and calcium (Ca) are present in concentrations significantly above other trace metals and are consistent with the analysis of the quinizarate being formed around primarily zinc (Zn) and copper (Cu). The source of the zinc (Zn) and copper (Cu) has not been conclusively determined, however DST consider the likely source to be wear from the labyrinth seals which contain a brazing alloy consisting of copper (Cu), zinc (Zn) and silver (Ag). The source of the calcium (Ca) has not been confirmed but is likely to be associated with whatever preservative fluid had been applied to the bearings. As a comparison, other trace elements associated with dynamic components that would be expected to be found in a helicopter engine lubrication system were also plotted (i.e. nickel (Ni), silver (Ag) and magnesium (Mg)). Nickel (Ni) is often found in low alloy and stainless steels. Silver (Ag) is a common plating material (especially for bearing cages) and magnesium (Mg) alloys are commonly used for housings in aviation propulsion systems. Iron (Fe) has not been included as it is typically observed in higher concentrations in all lubrication systems since the majority of load-bearing dynamic components are made from various steels.

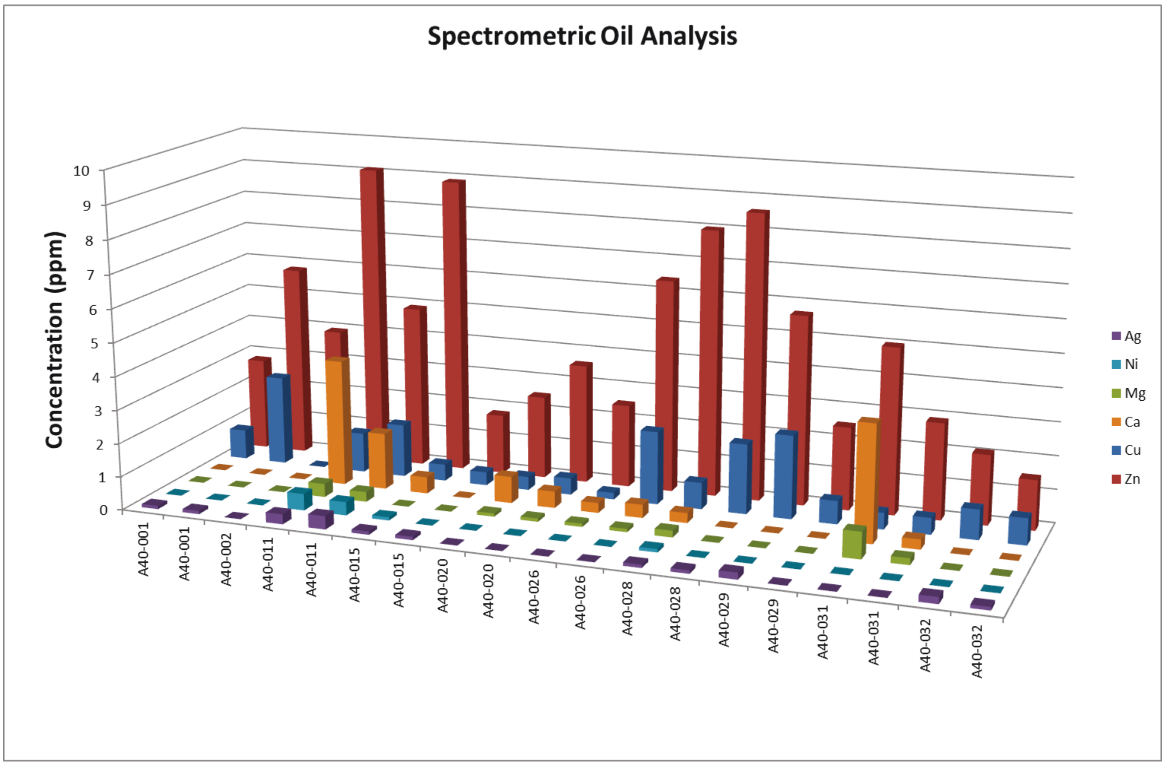


Figure 21: Spectrometric oil analysis results showing copper (Cu), zinc (Zn) and calcium (Ca) well above other elements expected

3.4 Compressor Wash Solutions

Initially it was suspected that compressor wash solution may be getting into the bulk oil. DST developed a method to identify the presence of indicator compounds found in the compressor wash base material. The observation of the compressor wash di-acid anticorrosion additives and alkly ethanolamide detergents in the bulk red substance also confirmed a contributory role of the compressor wash solutions (likely as a corrosion accelerator) in this contamination issue. A method was developed to detect the presence of the triethanolamine (TEA) which is a component of the compressor wash solutions (Appendix A). The method was successful in detecting the TEA in the oil samples examined.

3.5 Corrosion

3.5.1 Initial DST Bearing Inspection

As part of the initial investigation, DST staff visited Safran HE in Sydney on Tuesday 4 August 2015 to discuss the red substance accumulating on engine bearings and its apparent association with corrosion of the bearings. Rolling element bearings that had been extracted from RTM322 engine serial number 6526 were inspected during this visit. Engine 6526 had accumulated 565 operating hours since new[1].

The surfaces of the inner race, outer race, cage and rolling elements showed evidence of the red quinizarate substance. Areas where the quinizarate had been removed revealed localised deep pitting corrosive attack of the bearing steel which had occurred on the outer race (Figure 22), the inner race and the rolling elements. Dark staining of the silver-plated cage by the red quinizarate substance was also observed.

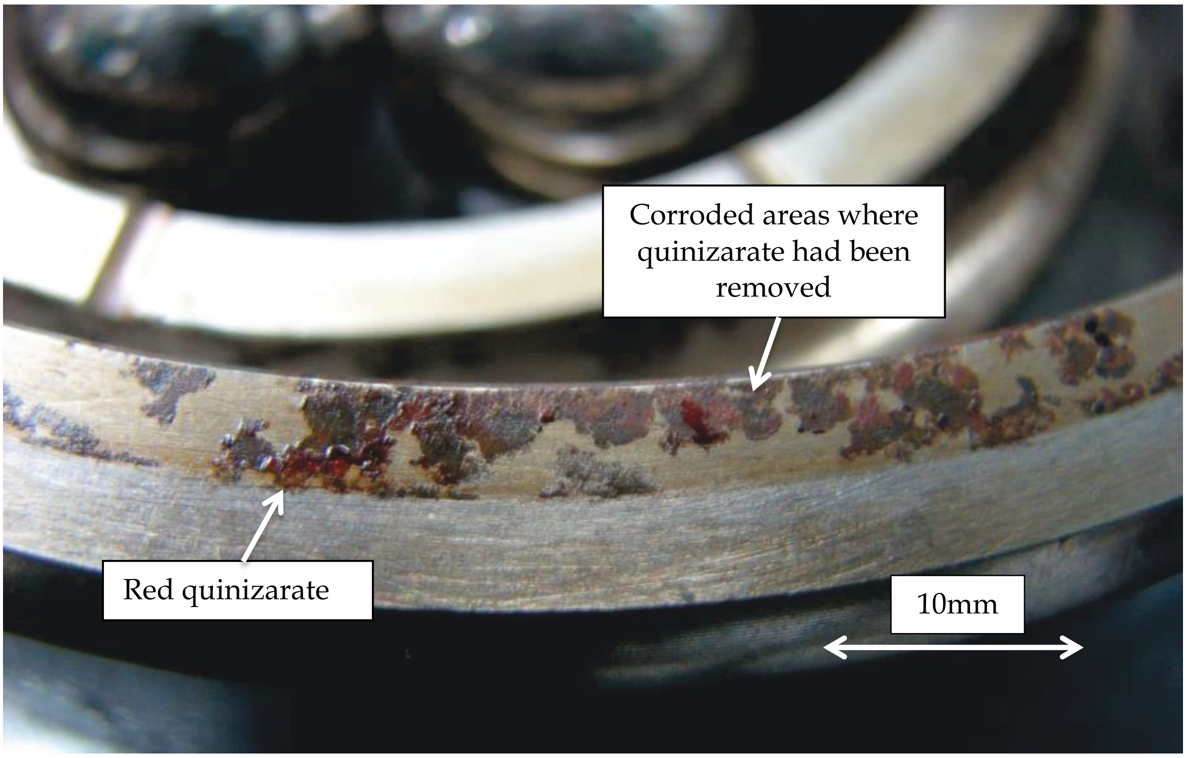


Figure 22 : Outer race of the bearing showing the red quinizarate substance and areas where it had been removed revealing the black coloured localised corrosion

The quinizarate / carboxylate salt mixture is a gelatinous material that forms a tenacious film on the surface of the low alloy steel bearing components. The local environment beneath the substance–steel interface becomes corrosive, typical of a crevice corrosion

[1] SNFA FRANCE F0771 SP 265/4 07RH6SA26 SER 625.

mechanism, where oxygen depletion occurs under the film forming an anodic reaction site and the surface of the steel in the region adjacent to the substance forming the associated cathodic reaction site. Removal of the film exposes the crevice corrosion beneath which has the appearance of pitting corrosion.

An adverse effect of this type of damage to the ball surfaces is that the sharp edges of the pitting corrosion can lead to mechanical damage of the inner and outer race contact surfaces leading to premature wear and potential failure of the bearing. Figures 23 and 24 show accumulated red quinizarate substances and localised black corrosion product on the inner and outer race of the bearing.

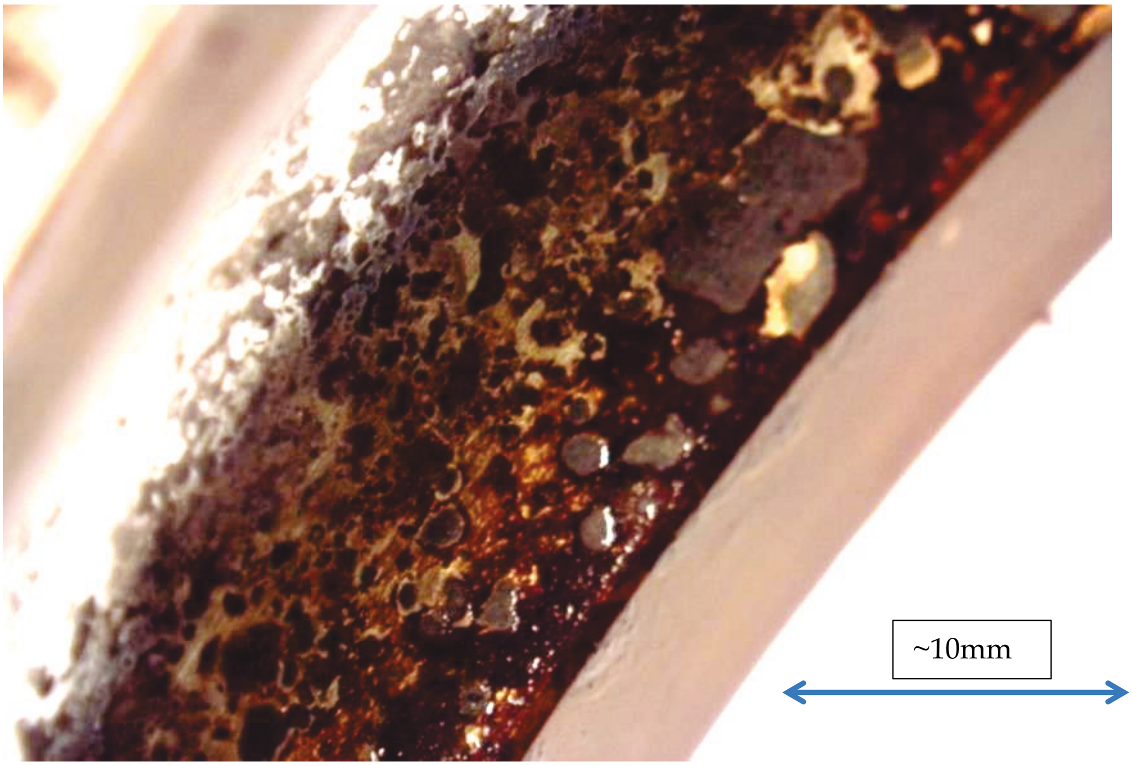


Figure 23: Outer race showing accumulation of red quinizarate substance and corrosion

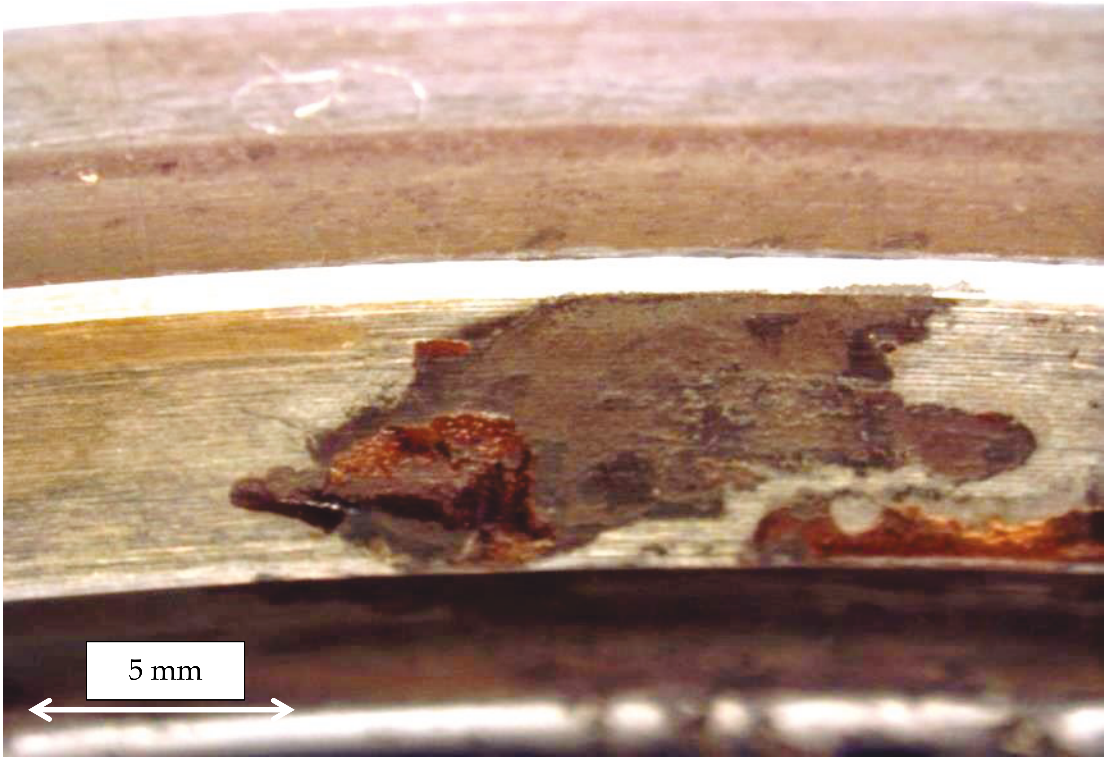


Figure 24: Red quinizarate substance and corrosion damage on the exposed surface of the inner race

3.5.2 DST Forensic Bearing Analysis

Another RTM322 main bearing[2] was provided to DST and subjected to a detailed forensic examination [6]. The bearing had been removed from Module 4 (M46526) of engine serial number 6526, with an accumulated life of 538 hours, due to the presence of magnetic chip indications resulting from extensive corrosion. The DST report confirmed extensive deep corrosion on all rolling elements, raceways and staining on cages consistent with the original observations during the Safran HE visit described in Section 3.5.1. Figures 25 to 27 show an example of a corroded ball from this bearing. Figure 25 is a macro image of the ball surface, while Figures 26 and 27 are SEM images at different high magnification showing the sharp edge pits observed. Note that the images of this bearing show it after cleaning and hence do not show the presence of the red substance. The inner and outer raceways also showed similar corrosion features as seen in Figures 28 and 29.

[2] SNFA F0771 SP 265/4 07RH6SA26 SER 623

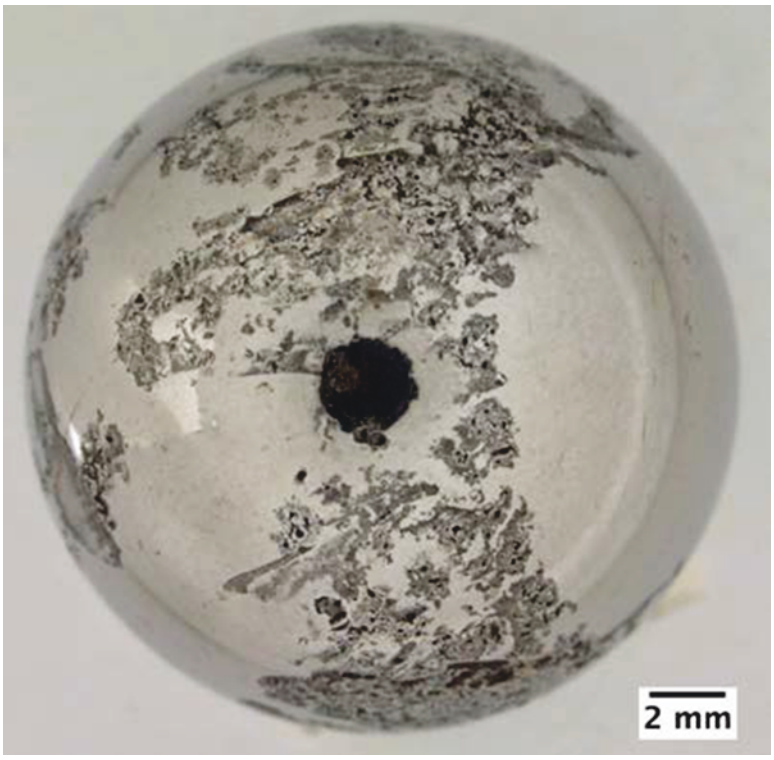


Figure 25: Rolling element from the subject bearing showing extensive pitting and surface corrosion

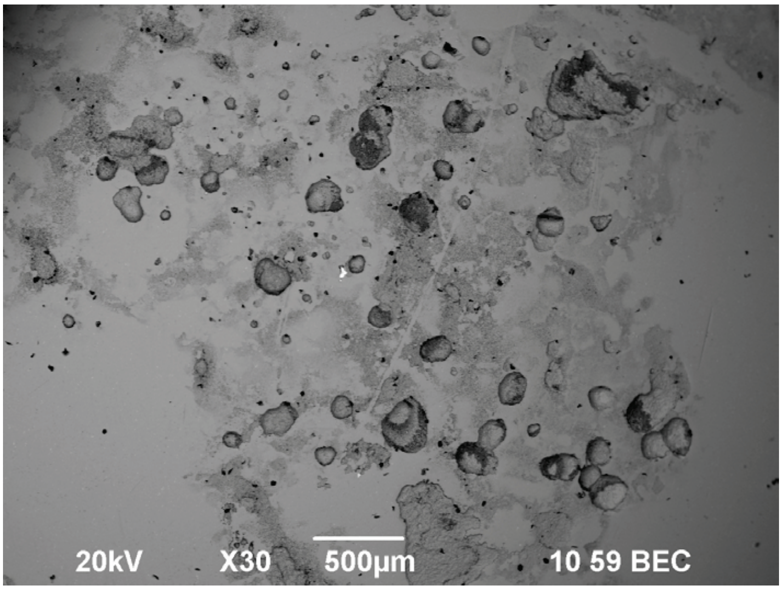


Figure 26: SEM image of the same rolling element from Figure 25 showing the deep pits

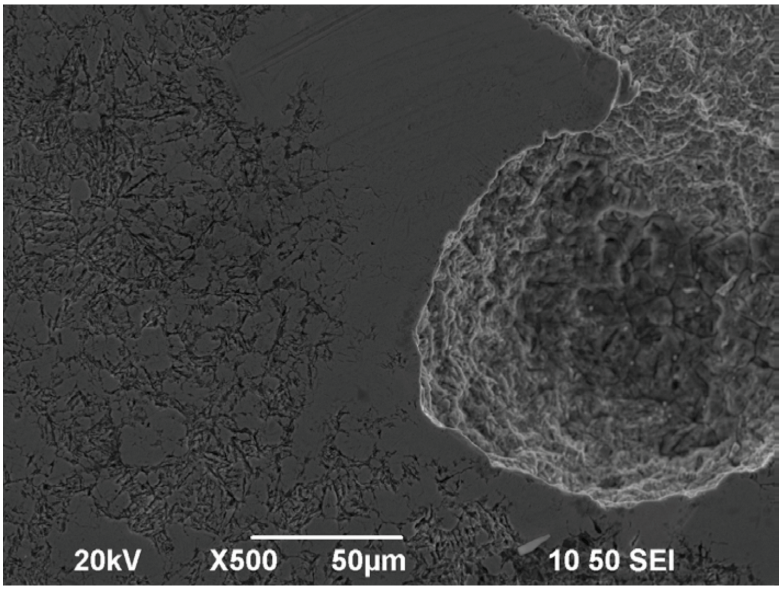


Figure 27: High magnification SEM image of the same rolling element from Figure 25 showing the surface corrosion and deep sharp-edged pitting

Figure 28: Split inner raceway showing extensive corrosion on the running surface and landings

Figure 29: Outer raceway showing extensive corrosion on the running surface and various landings

3.5.3 Bearing Steel

Two primary bearing steels are used in this engine: 100Cr6 (equivalent to AISI 52100) and E80DCV40 (equivalent to AISI M50), both of which are common bearing steels for aviation propulsion applications. The SNFA General Catalogue [7] advised that SNFA bearings are manufactured in SAE 52100 low alloy steel that is particularly clean and offers high reliability. It is hardened and tempered to a process which allows safe operation up to 150°C. Due to its excellent hardness and wear resistance SAE 52100 steel exhibits good fatigue life in rolling element bearings. However, the corrosion resistance of this steel is poor because of the relatively low chromium (Cr) content. Alloy steels with less than ~10% chromium (Cr) offer poor corrosion resistance. Generally, the surfaces of bearings made from traditional bearing steels must be protected with a coating of preservative fluid or lubricant to prevent corrosion. The typical chemical composition of the two primary bearing steels used in this engine are shown in Table 3.

The DST forensic report also identified corrosion on non-load bearing surfaces indicating that the corrosion may have been caused by a coating on the bearing. The typical fluids in contact with the entire bearing are either the lubricant (shown to be non-acidic) and preservative fluids (used between manufacture and installation). There was no other evidence observed to support a bulk lubricant issue in the subject engines.

Table 3: Primary alloying elements for the two common bearing steels in the RTM322 engine.

Element	**Composition (Wt%)**	
	100Cr6 [3] **(equivalent to AISI 52100)**	**E80DCV40**[4] **(equivalent to AISI M50** [5]**)**
Cr	1.35-1.6	3.75-4.25
Mo	-	4.00-4.50
V	-	0.9.-1.10
Mn	0.25-0.45	<0.35
Fe	Remainder	Remainder

[3] http://www.astmsteel.com/product/52100-bearing-steel-aisi/ accessed 22 February 2019.
[4] http://www.coroll.sk/Coroll_loziska/SNR_katalogy_files/02-Bearing_technology.pdf page 40 accessed 22 February 2019.
[5]http://www.matweb.com/search/datasheetText.aspx?bassnum=MSTM50A accessed 22 February 2019.

4. Airbus Helicopters Report

According to the Airbus Helicopters final report [2] released in May 2016 following the initial tranche of engine removals, 12 engines contained the red substance, of which six had been removed due to subsequent metallic debris caused by corrosion, one engine had been removed due to low oil pressure (likely related to red substance blocking the filter element) and the remaining engines remained in service as of mid 2016.

However, the Airbus Helicopters report did not satisfactorily address several critical features of this investigation, namely:

1. Why the red substance and corrosion were isolated to bearings within these engines;
2. Where the elevated levels of zinc (Zn) and copper (Cu) originated from; and
3. Why the phenomenon apparently only occurred in Australian aircraft given other MRH90 aircraft conduct similar compressor wash and desalination procedures.

Airbus Helicopters described the red substance as an "oil contamination" issue, however based on the evidence, DST do no agree that a bulk oil contamination issue was the primary cause. An abnormally high water level was only observed in one engine with two others being slightly elevated. The corresponding acid number of the oil across the affected engines did not show an issue with the bulk lubricant. This is a significant point and together with the localised nature of the corrosion does not support a generally high water content as the primary root cause.

Although the levels of zinc (Zn) and copper (Cu) did appear elevated compared to typical values, it is not clear whether this constituted bulk fluid contamination of residue from a localised internal issue such as metal liberated from seals wearing in. Therefore DST do not believe there is sufficient evidence to characterise this event primarily as a bulk fluid contamination issue. However it is likely that elevated water and compressor wash solution were contributing factors that may have accelerated the corrosion.

In 2018 the red substance issue re-emerged and resulted in at least seven unscheduled engine removals from four different aircraft in the ADF fleet. A Special Technical Instruction (STI) was subsequently issued on 16 October 2018 [3] to take oil samples, inspect magnetic chip detectors and inspect oil filter elements for the presence of the red substance. The ADF Wear Debris Analysis laboratory[6] continues to support this STI by conducting filter debris analysis and wear debris analysis of the affected filters in order to identify the presence and extent of bearing debris.

[6] This laboratory is a Defence Science & Technology Group and Defence Aviation Safety Authority collaboration)

4.1 Oil Replenishment Rigs

Airbus Helicopters initially suggested that a possible source of zinc and copper was the lubricant replenishment rigs used by 808 Squadron. At the time (relatively early in the initial investigation) DST agreed this was worth investigating. The hypothesis was that brass components in the rigs could potentially breakdown and be a source of the copper (Cu) and zinc (Zn) in the engine lubrication systems following top ups.

DST conducted an analysis of the fluid contained in the two replenishment rigs and found no evidence of zinc (Zn) or copper (Cu), however the rigs were subsequently quarantined. It is unlikely brass or a similar alloy was responsible for the copper (Cu) and zinc (Zn) concentrations since the approximate proportions were not consistent with brass and a plausible mode of degradation was never identified. Additionally, the same rigs were used for replenishing Main Gear Boxes with no adverse effects reported. DST therefore concluded that the replenishment rigs played no part in the red substance issue.

5. Possible Root Causes or Sources

During the investigation it became apparent that this issue was complex and involved more than one contributory cause. To assist with understanding the various results while retaining an overall context, a mind map was developed by DST (Appendix B). The mind map proved to be invaluable for keeping track of the various possible causes, testing results and enabled DST to communicate the complexity of the problem to other stakeholders. The localised nature of the red substance (quinizarate), the presence of carboxylate salts and the relatively good condition of most lubricants were all critical in determining the likely root cause.

There are at least three manufacturers that provide rolling element bearings for this engine (i.e. FAG-Schaefler, SNFA and SKF). All manufacturers state in their respective catalogues that there are potential incompatibilities between the bearing preservative fluid used prior to installation and synthetic lubricants as shown below:

> Compatibility issues with the bearing protection oil can arise when synthetic grease is used. Whenever possible, wash it with well filtered products compatible with the environment and the metal and dry it immediately after with dry and filtered compressed air. [8]

> The anti-corrosion agents in bearings with an oil-based preservative are compatible and miscible with lubricating oils having a mineral base. Compatibility must be checked if, for example, synthetic lubricants are to be used. If there is an incompatibility, wash out the anti-corrosion oil before greasing…[9]

> Normally, the preservative applied to new bearings does not need to be removed. It is only necessary to wipe off the outside and bore surfaces. However, if the lubricant to be used is not compatible with the preservative, the bearing should be washed and dried carefully. Bearings capped with seals or shields are filled with grease and should not be washed prior to mounting. [10]

No further details of the incompatibilities are provided and very little additional information was identified in the general literature. All bearing manufactures clearly state that the bearings must be washed with a suitable solvent prior to installation when being used with synthetic lubricants. It therefore seems plausible that the bearing preservative fluid had not been removed prior to installation in the affected engines. Clearly there was an adverse chemical reaction involving the MIL-PRF-23699 lubricant additives and the preservative fluid resulting in quinizarate formation and localised corrosion of the bearing steel. It is possible the carboxylate salt originated from compressor wash solution but this has not been confirmed and could have several possible sources.

6. Conclusion

This report has documented the DST contribution to the investigation of a red substance and associated corrosion of bearings experienced over two tranches in the ADF fleet of RTM322 engine. This contamination issue has resulted in a significant number of unplanned engine removals from the ADF fleet (initially in the RAN sub-fleet but ultimately in Australian Army aircraft as well). Whilst Airbus Helicopters delivered a final report into this issue in 2016 following the initial tranche of unscheduled removals, DST believe it did not adequately address the likely root cause nor explain the observed evidence.

Based on the available evidence, DST consider that the most likely primary cause of bearing failures in engines affected by the red substance (quinizarate) was an adverse reaction of a substance located only on the bearings (most likely a bearing preservative coating) with the synthetic lubricant and associated additives. Rolling element bearing preservative coatings used between manufacture and installation are clearly identified by bearing OEMs as having a potential incompatibility with synthetic lubricants.

The presence of either water and/or compressor wash fluid (in the form of carboxylic acids) in the bulk lubricant likely had a contributory impact on the corrosion, but could not have produced the localised damage by itself. Collectively, this resulted in the formation of the red quinizarate and a micro-corrosive environment around the bearings that subsequently led to corrosion of the bearings. Ultimately the liberation of metallic debris from corroded load-bearing surfaces resulted in the unscheduled removal of the engine in the majority of cases. Detection of compressor wash solution in the red substance was not considered sufficient to fully explain the observed evidence. If compressor wash solution and water content had been the only cause of this contamination issue, then corrosion would have been observed on adjacent low alloy steel components such as gears and shafts and this was not observed.

7. Recommendations

As a result of this investigation the following recommendations are made:

1. A thorough investigation be conducted by Safran Helicopter Engines to identify and confirm whether bearing installation processes for engines assembled for the Australian military fleet require new bearings to be washed with a suitable solvent prior to installation to ensure no residual preservation fluid remains.
2. Correct compressor wash procedures be adhered to minimise the potential for water and compressor wash solution to enter the lubricant system.
3. DST conduct or sponsor further research to ascertain the precise nature of incompatibilities between common bearing preservative fluids and common aviation synthetic lubricants.

8. Acknowledgements

The authors would like to acknowledge the assistance of, Mr Chris Wood and Mr Peter Stanhope.

9. References

1. Becker, A. and Rawson, P., Helicopter Transmission Oil Discolouration, DSTO-TR-2672, February 2012.
2. Airbus Helicopters, RTM322 Engine Oil System Contamination Investigation, Situation Report #5- Final Report, 26 May 2016.
3. STI-MRH90-355, Engine Oil System Inspections, 16 October 2018.
4. Rolls Royce Turbomeca (Safran HE Group) RTM322 Training Notes X 322 D9 960 2, November 2005.
5. ASTM 7898-14 Standard Practice for Lubrication and Hydraulic Filter Debris Analysis (FDA) for Condition Monitoring of Machinery.
6. Defence Science & Technology Group, DST-Group-CR-2016-0230, MRH90 Engine Bearing Corrosion Assessment, 2016.
7. SNFA General Catalogue 07/07/2014
8. SNFA (part of SKF Group) General Catalogue, page 54 https://gacol.pl/files/UserFiles/lozyska_precyzyjne_SNFA.pdf
9. FAG-Schaeffler Catalogue TPI 186 GB-D, Higher Performance Capacity Through the Use of Coatings, March 2013
10. SKF Bearing Mounting Guidance, https://www.skf.com/au/products/bearings-units-housings/principles/bearing-selection-process/sealing-mounting-dismounting/mounting-dismounting/mounting/index.html accessed 22 February 2019.

This page is intentionally blank.

Appendix A Method Developed to Investigate TEA

Oil samples from the MRH90 investigation were caustic extracted with NaOH. The aqueous layer was then acidified with HCl and back extracted with DCM. The organic layer was then concentrated and esterified with BCl_3 for later Gas Chromatography analysis for Fatty Acid Methy Esters. The remaining acidified aqueous phase was then investigated for Triethanolamine (TEA). The remaining HCl acidified aqueous sample was then evaporated to dryness in Petri dishes in the fume cupboard overnight. This left a salt residue which was then washed with minimal acetonitrile using a glass pipette. The acetonitrile was collected in a 40 mL glass vial. Approximately 100 µL of the silylation reagent tert-butyldimethylsilyl (TBDMS) was added to the vial which was then sealed and incubated for an hour at 60ºC. The sample once cooled was then transferred to a Limited Volume Insert (LVI) and analysed by GC-MS. A TEA reference standard was also prepared by dissolving 10 µL of TEA in 100 µL of acetonitrile adding 100 µL of TBDMS silylation reagent which was then incubated and prepared in the same way as the sample. A reference sample of the surfactant product ZOK27 was also similarly prepared.

The characteristic m/z 346 was used to perform extracted ion chromatograms to identify the TEA-$(TBDMS)_3$ derivative in the TEA standard chromatogram, which was identified at Retention Time (RT) 24.6 mins. The TEA-$(TBDMS)_3$ derivative was then identified in the MRH90 aqueous phase of the oil sample and the ZOK27 surfactant sample by RT (24.6 mins) matching and by comparison to the TEA reference standard mass spectra. TEA was therefore identified in both the MRH90 oil sample and the ZOK27 surfactant sample.

Appendix B DST Mind Map Used During Investigation

Australian Government
Department of Defence
Defence Science and Technology Group

Mind Map for MRH90 Engine Lube System Red Contamination – dated **4 December 2015**

Possible Cause 1: Preservative grease/liquid reaction with lube additive

1. Packing/preservative fluid incompatibility with synthetic lubes identified in SNFA, FAG and SKF catalogues.
2. Appearance seems to indicate a reaction of JO2 passivator additive (quinizarin) with an existing substance only present on the bearings.
3. Localised nature suggests not a bulk oil issue

Possible Cause 2: Comp Wash/ ZOK/ ARDROX contamination

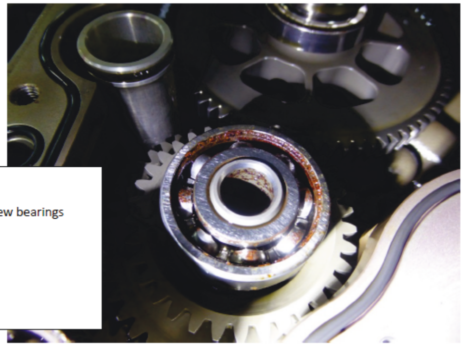
1. More frequent comp washes possibly contaminating lube system.
2. Samples of ARDROZ/ZOK tested? Results reported in DSTG minute
3. Some evidence of elevated water content (in-service limit for ADF aircraft = 1500 ppm. Test results: Rig 903 = 1108ppm, 905= 1075 ppm, A40-026 Eng 2 = 2665 ppm, A40-026 Eng 1 = 1085 ppm). Could this be due to low eng usage not driving water out?

Possible Cause 3: Replenishment Rig contamination/catalyst

1. ~~Replenishment rigs 903, 905 and 906 showed:~~
   a. ~~no elevated metal levels (SOA).~~
   b. ~~Acidity well below in-service limit of 2 mgKOH/g~~
   c. ~~Water content within the in-service limit of 1500 ppm.~~
2. ~~Rigs have been quarantined and physically removed from squadron.~~
3. ~~AGAP initiated oil sampling program~~
4. ~~Plasticizers identified in oil – unknown impact.~~

Known:

1. Red quinizarate limited to bearings – this is highly unusual.
2. Quinizarate/corrosion limited to bearings – no evidence on gears, internal casing etc
3. ADF use 3 brands of MIL-PRF-23699 oil: Mobil JO2, BP 2380 and Nyco Turbonycoil.
4. Preliminary investigation confirmed Nowra using JO2, Townsville using Turbonycoil (at 7 Sep 2015).
5. Metal passivators known for each oil:
   a. JO2 = quinizarin
   b. BP 2380 = benzotriazole
   c. Turbonycoil = quinizarin+benzotriazole
6. Navy do more comp washes than Army
7. Reported incompatibility between synthetic lubes and preservative fluid - SNFA catalogue & Schaeffler (FAG) catalogue
8. Moorman, J. W.,USN report on incompatibility of preservative fluid with synthetic hyd & lube oil – similar to our observations.
9. Quinizarate deposit forms tenacious film on bearing surface, crevice corrosion occurs at interface, which appears as pitting corrosion.
10. A40-029 tenacious substance Zn rich with Cu. Zn unusual.
11. USN in-service water limit 1000 ppm
12. Qunizarate metal ion confirmed as primarily Zn
13. Filter element mesh confirmed as aluminium alloy
14. Aeroshell 555 does not have ZDDP additive.
15. Zn present in all engines tested (AGAP oil analysis – Army & Navy)



Possible Further Actions:

- Review process of preservative fluid removal before installation of new bearings
- ~~Lower in-service water limit to 1000 ppm – alarms now in place~~
- Post wash drying run? AGAP confirm current practice satisfactory
- ~~Contact Mobil ?~~
- Experiments to confirm?

Discussion Points

1. What's different about Nowra and Townsville and world wide fleet?
2. If contaminant was part of bulk oil then we would expect to see evidence on gears, casing, tubes – only bearings
3. What fluid are the engines shipped to Australia in? Unlikely to be MIL-PRF-23699 – doesn't explain localised nature
4. What are the results of the TM investigation?
5. It is unclear whether Nowra and Townsville have brand-specific oil all of the time
6. If red substance was coming through bulk oil supply jets wouldn't the jets clog rapidly?
7. Could squadrons only use BP 2380?
8. Could squadrons us corrosion inhibiting JO2?
9. Approach SNFA for packing grease/oil specification?
10. What fluid are engines transported to Australia in lube system.
11. ~~Could 555 gearbox oil be contributing? Known additives? Search for ZDDP load carrying additive.~~
12. ~~Mobil/Exxon – worth contacting?~~
13. ~~ZOK/ARDROX – what else needs to be done?~~
14. Potentially coke observed as well?

Actions currently underway:

1. Broad oil analysis sampling (AGAP lead)
2. Forensic analysis of cleaned bearing (DSTG lead)
3. Analysis of aircraft 016, 029, 001 filters (DSTG lead)
   a. 001 most heavily contaminated with red substance
4. Analysis of SKF/FAG preservative fluid - pending delivery of unopened bearing. Results below from opened packages (DSTG lead)
   a. Dioctyl sebatate (plasticizer?) + ?
   b. SNFA preservative unknown
5. Review bearing installation practice/washing (TM Lead)
6. Contact Mobil for comment on quinizarate (DSTG)
7. Review TVL aircraft comp wash history (AGAP)
8. Investigate A40-001 filter element mesh material anomaly
9. Analysis of preservative fluid from SKF bearing
10. 1000 ppm water limit now in place

Outstanding Requests:

1. Uncleaned bearing showing red substance from next available engine.
2. ~~New SNFA bearing in packaging~~
3. TMF oil analysis results
4. Zinc Phosphate (Durotect Z) corrosion inhibitor used by Schaefler bearings – unknown if used on RTM322.

Australian Government
Department of Defence
Defence Science and Technology Group

Mind Map for MRH90 Engine Lube System Red Contamination – dated **4 December 2015**

DST Group currently exploring this hypothesis:

Residual rolling element bearing preservative fluid

+

Qunizarin additive + Zn

Forms

Red quinizarate

Carboxylate salt

Forms tenacious coating – may have caused bypass

Water in bulk fluid?

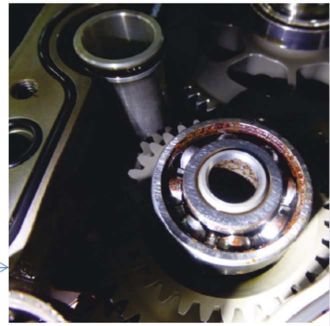
May be contributing factor/ catalyst

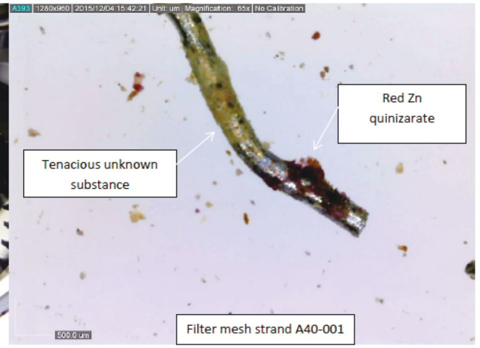
~~Heat?~~

~~May be contributing factor/ catalyst~~

ZOK/ ARDROX

May be contributing factor/ catalyst





- Explains localised corrosion
- Partially explains red "plaque" quinizarate
- Explains why localised to bearings only
- Schaeffler (FAG), SNFA and SKF bearing manufacturers warn against incompatibility of preservative fluid with synthetic lubricants
- May explain why only in Navy aircraft
    - Using Jet Oil 2 brand of 23699 (Army have used other brands)
    - Any usage difference? Perhaps Army have higher usage driving water out of bulk fluid?
- USN report (Moorman, 2001, NAWCADPAX/TR-2000/59) describes very similar phenomenon.

DEFENCE SCIENCE AND TECHNOLOGY GROUP DOCUMENT CONTROL DATA			1. DLM/CAVEAT (OF DOCUMENT)
2. TITLE RTM322 Engine Bearing Red Substance Contamination and Corrosion Investigation		3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED LIMITED RELEASE USE (U/L) NEXT TO DOCUMENT CLASSIFICATION) Document (U/L) Title (U) Abstract (U)	
4. AUTHOR(S) Paul Rawson, Andrew Becker, Jo-Anne Creek, Darren Gerrard and Cathy Smith		5. CORPORATE AUTHOR Defence Science and Technology Group Aerospace Division 506 Lorimer Street Fishermans Bend VIC 3207	
6a. DST GROUP NUMBER DST-Group-TR-3608	6b. TYPE OF REPORT Technical Report	7. DOCUMENT DATE June 2019	
8.TASK NUMBER AIR 17/584	9.TASK SPONSOR Director General Fuel Services	10. RESEARCH DIVISION Aerospace Division	
11. MSTC Aircraft Health and Sustainment		12. STC Engine and Fuel Integrity	
13. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT *Approved for public release.* OVERSEAS ENQUIRIES OUTSIDE STATED LIMITATIONS SHOULD BE REFERRED THROUGH DOCUMENT EXCHANGE, PO BOX 1500, EDINBURGH, SA 5111			
14. DELIBERATE ANNOUNCEMENT No limitations			
15. CITATION IN OTHER DOCUMENTS Yes			
16. RESEARCH LIBRARY THESAURUS Aircraft Engines, Lubrication, Contamination, Ball Bearings			
17. ABSTRACT DST were asked to investigate the nature and cause of a red gelatenous substance observed in the lubrication system of several RTM322 engines fitted to ADF MRH90 Taipan helicopters. The contaminant and associated corrosion had been responsible for the unscheduled removal of several engines from the ADF fleet in two tranches over a period of approximately 3 years. This report describes the analysis conducted by DST and discusses a plausible cause for the contamination.			