HELLENIC REPUBLIC

MINISTRY OF INFRASTRUCTURE & TRANSPORT

# AIR ACCIDENT INVESTIGATION AND AVIATION SAFETY BOARD (AAIASB)

REPORT
ON THE INVESTIGATION OF A SERIOUS INCIDENT
INVOLVING THE AIRCRAFT SX-IFR
AT THE AREA OF AMIGDHALEON, KAVALA
ON THE 2nd OF MARCH 2017

E 01 / 2019

**REPORT**
**ON THE INVESTIGATION OF A SERIOUS INCIDENT**
**E 01 / 2019**

**Serious incident involving the Aircraft SX-IFR**
**at the area of Amigdhaleon, Kavala**
**on the 2nd of March 2017**

**The serious incident investigation was carried out by the Air Accident Investigation and Aviation Safety Board in accordance with:**

- **ICAO Annex 13;**
- **Regulation (EU) No. 996/2010;**
- **Hellenic Republic Law No. 2912/2001.**

*'In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No. 996/2010 and Law No. 2912/2001, the purpose of investigations into aviation accidents and incidents is not to apportion blame or liability. The sole objective of the investigation and its findings is the prevention of accidents and incidents.*
*As a result, use of the findings for any purpose other than the prevention of future accidents could result in erroneous conclusions.'*

**The Air Accident Investigation and Aviation Safety Board**

**Chairman**

**Antonios Athanasiou**

**Members**

**Akrivos Tsolakis**
Captain, Air Safety Investigator

**Grigorios Flessas**
Captain

**Nikolaos Tikas**
Computer and Software Engineer

**Panteleimon Mpotsaris**
Professor of Democritus University of Thrace

**Secretary: K. Katsoulakis**

## LIST OF CONTENTS

| | |
|---|---|
| **OPERATOR** | : EGNATIA AVIATION LTD. |
| **OWNER** | : FICOSA LTD |
| **MANUFACTURER** | : DIAMOND INDUSTRIES GmbH |
| **MODEL** | : DA40NG |
| **COUNTRY OF MANUFACTURE** | : AUSTRIA |
| **NATIONALITY** | : HELLENIC |
| **REGISTRATION** | : SX-IFR |
| **PLACE OF OCCURRENCE** | : AMIGDHALEON, KAVALA |
| **DATE & TIME** | : Thursday 02/03/2017 at 09:03 h |
| Note | : All times are local (local time = UTC + 2h) |

## SYNOPSIS

On 02/03/2017, the aircraft under registration SX-IFR owned by "FICOSA LTD" and operated by "EGNATIA AVIATION LTD" with registration SX-IFR, during a training flight from the airport of Kavala (LGKV), experienced an engine failure and landed safely at Amigdhaleon inactive military airport (LGKM).

The Air Accident Investigation and Aviation Safety Board was notified of the incident on the same day and appointed an investigation team under document AAIASB/723/06-03-2017.

On 31/03/2017, a "Notification to International Authorities" was issued and on 07/04/2017 the state of manufacture appointed an accredited representative (ACCREP).

# 1 FACTUAL INFORMATION

## 1.1 History of the Flight

The aircraft took off at 08:38h from the Airport of Kavala (LGKV) with destination the North Training Area located N-NW of the airport. At the south border of the area there is the Amigdhaleon military airport (LGKM) which, even though not active, is host to a small Hellenic Air Force contingent based in Chrysoupoli. This was a training flight of a duration of three hours and thirty minutes, finally destined back to the airport of Kavala (LGKV). About 5 nautical miles north of LGKM airport at about 08:51 h the pilot, at an altitude of 2.500 ft and with the aircraft on the climb phase from 2.000 ft to 3.000 ft, experienced engine power loss, vibration and oil smell within the cockpit. Immediately there was a low oil pressure warning on the G1000 glass cockpit. After that, the pilot declared an emergency situation to the Air Traffic Controller at LGKV airport and his intention to land at Amigdhaleon military airport (LGKM), which he did. According to the pilot’s statement, the flight, from the time the incident occurred until the aircraft landing, lasted approximately three minutes and during the said time period, the engine power loss did not create problems in aircraft maneuverability.

Immediately after landing, the pilot stopped the aircraft on the runway and switched off the engine to avoid any further damage to it, as well as to prevent fire from breaking out.

Two engineers from the aircraft’s certified maintenance organization arrived onsite at Amigdhaleon military airport and after inspecting the engine they detected oil leakage from the oil separator breather line (Photo 1). After replacing the torn hose (Photo 2) with a new one, cleaning the engine and filling the engine with oil, a ground run was performed during which vibrations and white smoke from the exhaust pipe were noted; upon full power check, the engine performed at only 65% of its power rating. After the engine run, the engineers manually rotated the propeller of the aircraft and detected three rather than four compressions; therefore, one of the four cylinders had sustained damage and the engine had to be replaced.


**Photo 1:** The oil separator breather line hose

**Photo 2:** The torn hose of the oil separator breather line after its removal from the engine

## 1.2 Injuries to Persons

| Injuries | Crew | Passengers | Others |
|---|---|---|---|
| Fatal | --- | --- | --- |
| Serious | --- | --- | --- |
| Minor/None | -- / 02 | -- / -- | -- / -- |

## 1.3 Damage to the Aircraft

The aircraft sustained no damage of any kind, other than the engine.

## 1.4 Other Damages

Not applicable

## 1.5 Personnel Information

The pilot was a 63-year old male.

| | |
|---|---|
| License | : Part-FCL CPL(A)/PPL(A) license No. GBR.FCL.CP.244400C.A, valid, originally issued on 13/08/2008. |
| Endorsements | : Single Engine Piston-SEP Airplanes (land), valid until 31/10/2018. Flight instructor FI(A) rating, valid until 31/10/2019. |
| Medical Certificate | : Class 1 and 2, valid until 03/08/2017 and 03/02/2018 respectively. |
| Flying Experience | : The pilot had a total of 7.376 flying hours. |

The trainee was a 20-year old male.

| | |
|---|---|
| License | : Private Pilot License No. PA10214 issued in Jordan valid until 14/03/2019, originally issued on 15/03/2016. |
| Medical Certificate | : Class 1, valid until 31/01/2018 and Class 2, valid until 31/01/2022. |

## 1.6 Aircraft Information

### 1.6.1 General

DA40NG is a four-seat (including the pilot's seat) single-engine, propeller-driven aircraft, constructed from composite materials by *Diamond Aircraft Industries*, fitted with advanced electronic navigation and communication systems and used as a training aircraft.


**Photo 3:** The aircraft parked at LGKM airport

### 1.6.2 Aircraft

| | |
|---|---|
| Manufacturer | : DIAMOND INDUSTRIES GmbH |
| Model | : DA40NG |
| Manufacturer’s serial No. | : 40.N027 |
| Year of manufacture | : 2011 |
| Maximum Takeoff Mass (MTOM) | : 1.280 kg |
| Total flight hours since new (TSN) | : 3.198 |
| Total No. of Landings | : 3.447 |
| Certificate of Registration | : Issued on 23/06/2011. |
| Airworthiness Certificate | : Issued on 23/06/2011. |
| Airworthiness Review Certificate | : Valid until 22/06/2017. |
| Aircraft Radio Station License | : Valid until 28/06/2017. |
| Noise Certificate | : Issued on 22/07/2011. |
| Certificate of Insurance | : Valid until 25/05/2017. |

### 1.6.3 Engine

| | |
|---|---|
| Manufacturer | : AUSTRO ENGINE GmbH |
| Type | : E4-A |
| Serial Number | : E4-A-00189 |
| Maximum Power Output / RPM | : 123.5 KW / 3.880 RPM |
| Time since new (TSN) | : 1.698,5 |
| Time Between Overhaul | : 1800 (+/-50) h or 4380 (+/-30) days |

### 1.6.4 Propeller

| | |
|---|---|
| Manufacturer | : MT-PROPELLER ENTWICKLUNG GmbH |
| Type | : MTV-6-R/190-69 |
| Serial Number | : 110161 |
| Time since new (TSN) | : 984,7 |

### 1.6.5 Maintenance

The Continuous Airworthiness Management Organization under Reg. No. EL.MG.0066 was responsible for the management of the aircraft airworthiness and aircraft maintenance was conducted by the certified maintenance organization under Reg. No. EL.MF.0002, qualified to conduct Line and Base maintenance operations for this specific type of aircraft.

The engine had been installed on 13/12/13 and had operated 51 hours since its last 100-hour inspection, in which the Oil Separator Breather Line Hose had been inspected.

There was no entry in the aircraft’s technical logbook about any mechanical problem, and there have been no reports by the pilot for any failure.

### 1.6.6 Fuel

The fuel used was Jet A1 and the results of the fuel sample analysis conducted by a local certified laboratory on 07/01/2016 found with no deviations from specifications.

### 1.6.7 Lubricants

The engine oil used was CASTROL EDGE 0W-40 A3/B4 Q3. The analysis of an oil sample, conducted by a certified laboratory in Italy on 10/06/2016, and the results thereof revealed no deviations from specifications.

## 1.7 Meteorological Information

According to the local weather report (METAR) for the day and time of the incident,

| |
|---|
| LGKV 020650Z 00000KT 9999 FEW016 BKN025 BKN080 09/08 Q1010= |
| LGKV 020720Z 00000KT 9999 FEW016 BKN025 BKN080 09/08 Q1010= |

prevailing visibility was greater than 10 km, few clouds, wind: calm, outside temperature 09°C, dew point 08°C, barometric pressure 1010 hPa (29,82 in Hg).

### 1.8 Aids to Navigation

Not applicable.

### 1.9 Communications

The captain used the frequency of the Control Tower of Kavala Aerodrome (LGKV) at 118.400 KHz.

### 1.10 Aerodrome Information

Amigdhaleon military airport (LGKM), even though not active, is host to a small Hellenic Air Force contingent based in Chrysoupoli. It has an asphalt-paved runway measuring 1.625 m x 30 m, 70,12 m above MSL, reference point coordinates 40°58΄00΄΄N and 024°21΄00″E. The airport handles VFR flights, and for fire-fighting purposes (RFFS) it is classified as MIL CAT 6.

### 1.11 Flight Data Recorders

#### 1.11.1 Flight Recorders

The aircraft is equipped with an EECU (Engine Electronic Control Unit) system and its recordings have been submitted to the engine manufacturer for further analysis.

#### 1.11.2 Aerodrome Control Tower Recorder

Not applicable.

### 1.12 Wreckage and Impact Information

Not applicable.

### 1.13 Medical Information

Neither of the two persons onboard the aircraft was injured.

### 1.14 Fire

Not applicable.

### 1.15 Survival Aspects

Not applicable.

### 1.16 Tests and Research

The engine was sent to the manufacturer (Austro Engine GmbH) for inspection which revealed a crack on the piston of No. 4 cylinder, as well as wear (channel for combustion gas escape from the cylinder liner through the oil groove and the ring grooves of the piston) (Photos 4 & 5). For this reason, the damaged piston was sent for further investigation to a specialized laboratory (OGI-Austrian Institute for castings) in order to identify the causes for its crack and wear (Appendix 1).

Furthermore, the fuel injectors were sent for inspection to a specialized repair center, where it was found out that the injector of No. 4 cylinder had a higher fuel flow rate than the specified limit.


**Photo 4:** Side view of No. 4 cylinder


**Photo 5:** Top view of No. 4 cylinder

## 1.17 Organizational and Management Information

Egnatia Aviation Ltd. is one of the largest flight training organizations in Greece and Europe offering commercial pilot training courses, certified by EASA and based at the International Airport of Kavala (LGKV). It was founded in July 2006 and in the last ten years more than 1.000 students from 54 countries have graduated from this academy. The company operates a fleet consisting of single-engine aircraft Diamond DV20 Katana, Diamond DA40NG and twin-engine Diamond DA42 equipped with the Garmin 1000 Glass Cockpit, and the new aircraft AERO AT-3 equipped with analog instruments. Recently the School acquired a state-of-the-art Alsim ALX simulator.

## 1.18 Additional Information

Not applicable.

## 1.19 Useful or Effective Investigation Techniques

Not applicable.

# 2 ANALYSIS

The inspection of the aircraft maintenance records revealed that maintenance was performed according to the approved maintenance program and there was no Airworthiness Directive outstanding that could have contributed to the engine failure. Moreover, the engine operating time was within the limits specified for overhaul according to the maintenance program.

The oil separator breather line hose (P/N E4A-53-100-501) that was installed to the engine, was in accordance to the Illustrated Parts Catalog and its condition had been checked during the last 100-hour inspection, i.e. 51 hours prior to the incident, without any findings.

The results of the inspection of the fuel injection nozzles conducted by an authorized repair center, showed that the nozzle of No. 4 cylinder, had a higher fuel flow rate than the limit specified. This resulted in an increased thermal stress for the piston at this particular cylinder.

When the engine was disassembled, a crack was found at the piston of No. 4 cylinder, which (crack) started at the piston crown and ended to the piston’s pin hole. The inspection of the piston of No. 4 cylinder which conducted by a specialized laboratory (Appendix 1) showed that the crack initiation site presented no micro-construction or mechanical defects. Moreover material hardness, checked at the crack initiation site of the said piston, was 82 HB indicating a local weakening of the piston’s aluminum alloy caused by the thermal stress during engine operation, to which the increased fuel supply by the injection nozzle of the said cylinder may have contributed.

Furthermore, according to the conclusion reached by the laboratory that performed the tests at the piston of No. 4 cylinder, crack initiation at the weakened piston site is caused by fatigue (fatigue crack) due to overloading. The loads involved are most likely due to the piston's bending movement which is perpendicular to the piston's pin axis.

It was also revealed that the crack provided an escape route for the combustion gases from the inside of the cylinder through the oil groove and the ring grooves of the piston. This path of the combustion gases gradually formed a wider escape channel for the combustion gases between the cylinder and the ring grooves of the piston. Furthermore, two more cracks were also found, one at the entry to the combustion gas escape channel and the other one from its middle to the pin hole.

After the incident, and following the replacement of the torn oil separator breather line hose with a new one and the filling of the engine with oil, a ground run was performed during which engine vibrations were noted (as experienced during the flight prior to the incident) as well as white smoke from the exhaust pipe. Such vibrations combined with the escape of combustion gases from No. 4 cylinder via the escape channel formed as a result of the piston crack and further operation of the engine, may have led to the fatigue and failure of the oil separator breather line hose.

# 3 CONCLUSIONS

## 3.1 Findings

**3.1.1** Weather conditions were not a contributing factor to the incident.

**3.1.2** The instructor and the trainee were correctly licensed and qualified to conduct the flight.

**3.1.3** Aircraft maintenance was being performed according to the approved maintenance program, without any pending items.

**3.1.4** The aircraft was airworthy and all required certificates were valid.

**3.1.5** The engine's fuel and oil were within specified limits.

**3.1.6** The piston of No. 4 cylinder was manufactured in accordance with the manufacturer's specifications.

**3.1.7** The fuel injector of No. 4 cylinder had a fuel flow rate higher than the specified limit.

**3.1.8** It was found that the aluminum alloy was weakened due to thermal stress at the crack initiation site.

### 3.2 Probable Causes

The supply of fuel at a rate higher than the specified limit by the fuel injector of No. 4 cylinder contributed to the thermal stress of the piston of No. 4 cylinder, resulting in the formation of a fatigue crack.

### 3.3 Contributing Factors

Not applicable.

## 4 SAFETY RECOMMENDATIONS

Not applicable.

Nea Philadelphia, 06 June 2019

| THE CHAIRMAN | THE MEMBERS |
|---|---|
| Antonios Athanasiou | A. Tsolakis |
| **Exact Copy** | G. Flessas |
| **The Secretary** | |
| | N. Tikas |
| Kyriakos Katsoulakis | P. Mpotsaris |

# 5 APPENDIX

Österreichisches Gießerei-Institut
Parkstraße 21, 8700 Leoben, Austria
Tel.: +43 3842/431010
Fax.: +43 3842/431011
office@ogi.at, www.ogi.at

## Examination Report

## Failiure analysis of a broken piston

| | |
|---|---|
| **Customer:** | **Austro Engine GmbH**<br>Rudolf-Diesel-Straße 11<br>2700 Wiener Neustadt |
| **Report to:** | Mr. Nicolas Maciej |
| **Tel.:** | +43 (0) 2622 - 23000 - 2557 |
| **Fax.:** | +43 (0) 2622 - 23000 - 2711 |
| **E-Mail:** | n.maciej@austroengine.at |
| **Ordered by:** | Denise Pertl |
| **Order date:** | 09.05.2017 |
| **Customer Order No.:** | EP0161458 |
| **Sample received on:** | 09.05.2017 |
| **Carried out by:** | DI Bernd Panzirsch |
| **Department:** | Nonferrous / Failure analysis |
| **ÖGI-task-no.:** | 56.653 |
| **Date of report:** | **30.05.2017** |

Verein für praktische Gießereiforschung
**Österreichisches Gießerei-Institut**
Vorstandsvorsitzender
KR Ing. Peter Maiwald
**Geschäftsführer**
Univ.-Prof. DI Dr. Peter Schumacher
DI Gerhard Schindelbacher

Bankverbindung: UniCredit Bank Austria AG
IBAN: AT08 1100 0009 1735 7600
BIC: BKAUATWW

UID-Nr.: ATU29756305
ZVR-Zahl: 283242682

METALL IM FOKUS

## 1 Scope of examination

From Austro Engine GmbH a piston which exhibits a crack has been sent for investigations in order to analyse the cause for the existence of cracking.

The piston was mounted in engine E4-A-001889 at the 4th cylinder.

## 2 Investigations

The situation of the broken piston at receipt is given in fig. 1 to 7.
Additionally to the crack, the piston crown shows some imprints by foreign particles, which have been exemplary documented in figures 7, 8, 29 and 30. The imprints are not correlating with the fracture location (fig. 9). Additionally a gas channel has been generated between the combustion bowl and the ring grooves (fig. 7 and 10).

### 2.1 Fracture analysis

The piston suffered a crack which is orientated nearly parallel to the piston pin axis and which separated half of the piston crown between inlet-and-outlet valve pockets (fig 7). The location of the crack does not correlate with the injection spots on the crown (fig. 8 and 10).

On the outer diameter of the piston, where the ring package is positioned, the crack splits the top area of the piston until the piston pin bore and follows the bore towards the centre of the piston where the crack stopped in the middle of the piston (fig. 11 and 12). There the edge of the crack can be observed in the middle of the cone of the combustion chamber (fig. 8).

The crack of the piston has been carefully cut open in order to be able to analyse the fracture surface, which shows three individual fracture areas (Fig. 13, 14 and 21 and 22).

The main and primary fracture is a fatigue fracture starting at the inner radius of the crown opening into the combustion chamber bowl (at the transition radius from the crown to the bowl, fig. 15 and 16). At the fracture origin no mechanical damage or any notch–like defect can be detected (fig. 17 and 18).

From the fracture origin the crack propagated towards the piston pin bore, separating half of the piston (fig. 15). When reaching the bottom of the combustion chamber bowl the crack obviously linked the bowl with the cooling channel and (further on) the ring grooves. The hot combustion gases followed the crack and melted the aluminium in the vicinity, thereby creating a gas channel between the combustion chamber bowl and the ring grooves. Subsequently the channel was widened by hot gases blowing through the gap.

Two further fatigue fracture areas occurred between this gas channel and the piston pin bore, both showing their origin at the edges of the gas channel – one at the entrance and

the second one near the oil ring groove (fig. 19 and 20) - and therefore are interpreted as subsequent cracks.
In the SEM (Scanning Electron Microscope) no further details could be detected due to a layer of contaminations, which could not be removed by intense ultrasonic cleaning (fig. 23 and 24).

The location and the orientation of the crack has been influenced by bending loads which are increased normal to the axis of the piston pin, as the pin itself supports the stiffness parallel to its axis. These bending loads most probably resulted in a local stress situation within the area of the fracture origin.

### 2.2 Hardness Measurements

Hardness measurements have been implemented on the surface of the piston crown between the outlet valve pocket and the crack, showing a hardness of 90 HV30 (resp. approximately 85 HB) next to the crack, with a decrease of hardness within the area of the local injection spot (75 to 85 HV, 71 to 81 HB) and towards the valve pocket (75 HV30, approximately 71 HB, fig. 27).

A metallographic cross section has been prepared to investigate the microstructure, which does not expose any relevant deviation concerning the crack appearance (fig. 8). On this cross section a further hardness measurement was performed to see the hardness distribution from the crown towards the piston pin bore. The results of the hardness measurements are given in figure 28.
The hardness increases from 82 HB underneath the top surface of the crown to approximately 106 HB in a distance/depth of ~ 9 mm from the top face of the crown, measured along the surface of the combustion bowl. Therefore the fracture induction took place in a region of the piston, where the hardness is decreased due to the thermal impact during operation. The local hardness measured next to the fracture induction is approximately 82 HB.

As no further damage at the surface or within the microstructure of the piston is detectable at the fracture origin (fig. 25 and 26), it is suggested, that local overloads, resulting from the bending loads described above, have introduced the fatigue fracture supported by the weakening of the material by thermal impact.

### 2.3 General observations

Wear traces at the pistons skirt and in the area of the ring package can be traced up to the piston crown. To a certain extend this is a consequence of the oily residuals of the combustion process, which fill the gap between piston and cylinder.

It should be investigated, whether these residuals in the gap between piston crown and cylinder are responsible for possibly higher frictional forces causing additional bending and as a consequence additional stresses within the area of the main fracture induction.

## 3 Summary and Conclusion

The piston, which suffered a crack, has been investigated by stereomicroscopy, SEM, metallography and hardness measurements.

The crack of the piston, which has been induced at the transition radius from the crown to the combustion bowl, propagated parallel to the piston pin axis towards the piston pin bore separating half of the piston from outer diameter to the central cone. There is no local correlation between the injection spots or imprints in the crown by foreign particles and the crack. The character of the crack is that of a fatigue fracture.

At the fracture origin neither microstructural nor mechanical defects are existent. The hardness measured at the crack induction area is approximately 82 HB indicating a local softening of the aluminium-alloy due to the thermal impact during engine run.

When the crack propagated from the crown towards the piston pin bore it linked the oil groove and further the ring grooves with the combustion chamber bowl offering the combustion gases a gap to follow. As a consequence a gas channel between the combustion chamber bowl and the ring grooves occurred and gradually widened during engine run.
At the edges near the entrance of the gas channel and at half length of the gas channel two further fatigue cracks appeared separating the area of the piston below the gas channel until the piston pin bore.

Summing up the investigations the fatigue crack was induced due to overloading a thermally weakened material. The loads are most probably resulting from the bending movement of the piston normal to the piston pin axis.
Whether deposits from the combustion, which can be found at the crown on the outer diameter of the piston in the area of the ring package, have increased the loads due to additional frictional forces cannot be stated and should be further examined.

Imprints in the top face of the piston crown can be detected but they are not regarded as cause for the crack induction as their location does not correlate with the fracture induction.

This examination report with our task-no.: 56.653

| | | | | |
|---|---|---|---|---|
| Consists of | 5 Text pages | -- Tables | 30 Figures | -- Enclosure. |

Managing Director: Univ. Prof. DI Dr. Peter Schumacher

Technical Responsibility: DI Bernd Panzirsch


56653_01_02

Fig. 1: Overview of the piston mounted at the fourth cylinder


56653_01_06

Fig. 2: Overview of the piston, top face (crown)


Fig. 3: Overview of the piston, skirt


Fig. 4: Overview of the piston, side view


Fig. 5: Overview of the piston, skirt


Fig. 6: Overview of the piston, side view


Fig. 7: Overview of the piston; the crack and the entrance of the gas channel are marked

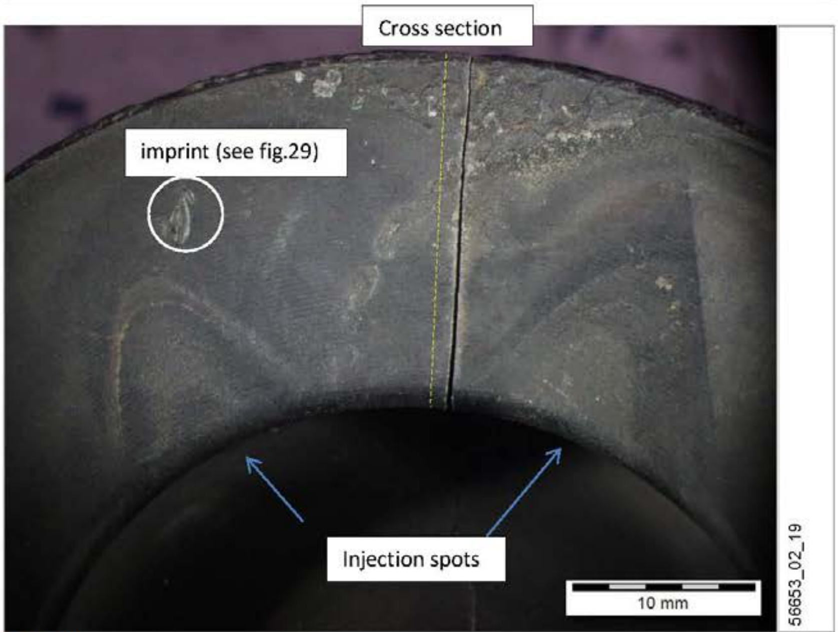



Fig. 8: Top face (crown); the crack separates the crown; injection spots next to the crack do not correlate with crack location; there are imprints visible, which are located further off the crack.

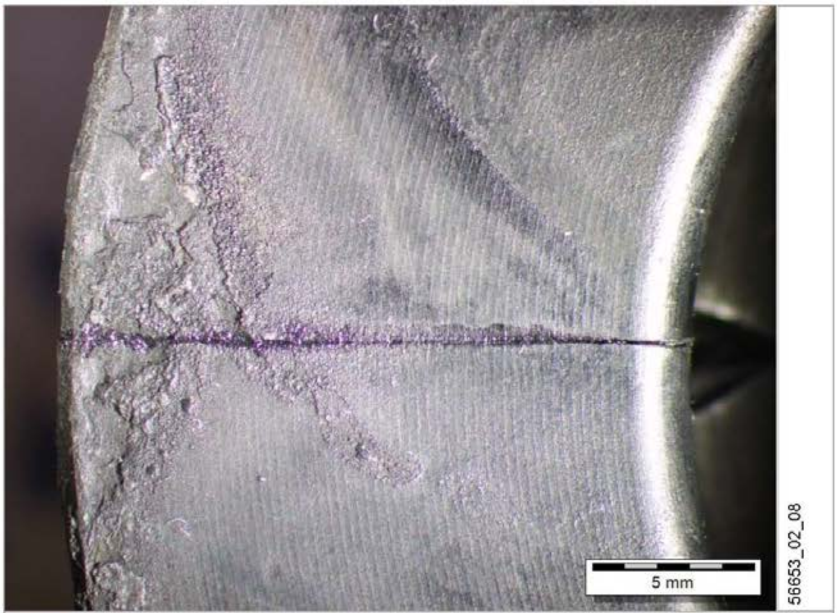



**Fig. 9:** Overview of the crack in the piston crown; no imprints correlate with the crack

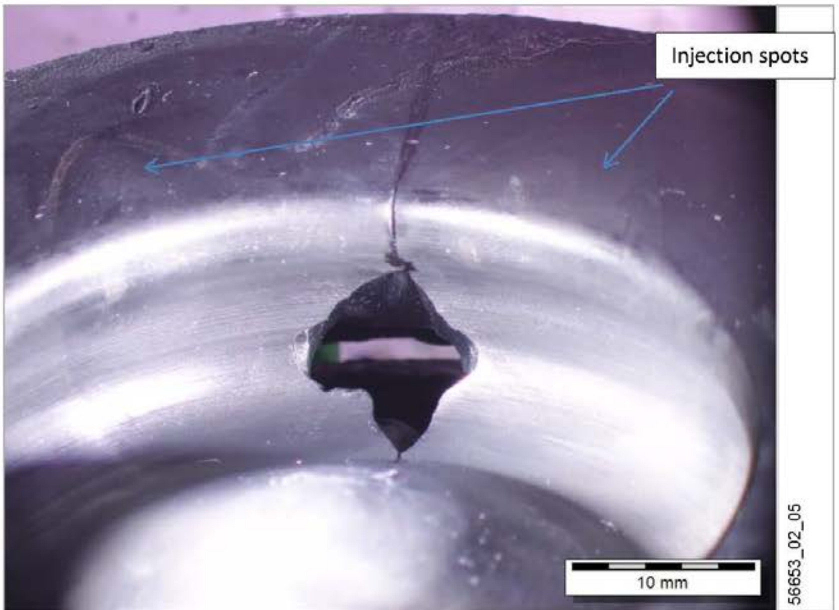
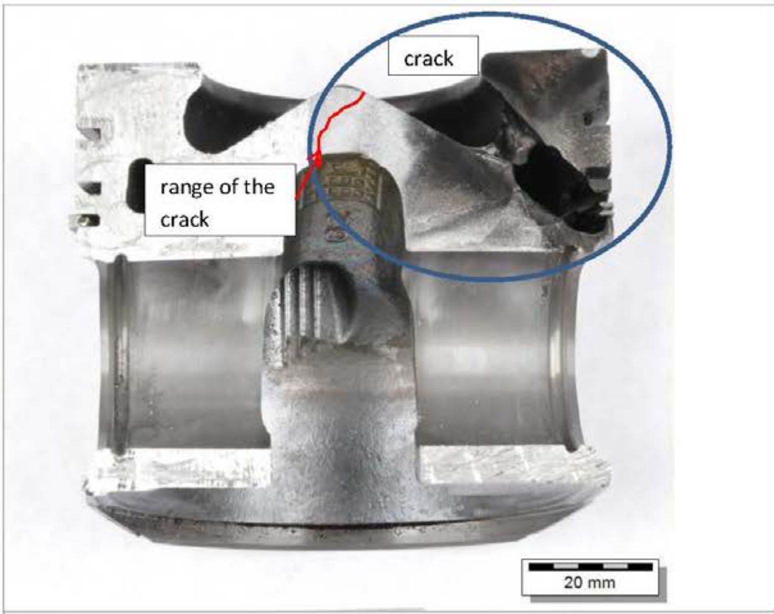



**Fig. 10:** Overview of the crack in the piston crown and gas channel; no correlation with the injection spots


Fig. 11: Following the crack at the outer contour until it meets the piston pin bore


Fig. 12: The crack follows the piston pin bore until the centre area (central cone)




56653_01_22

**Fig. 13:** Overview of the opened crack


56653_01_23

**Fig. 14:** Overview on the opened crack (counter surface to fig. 13)

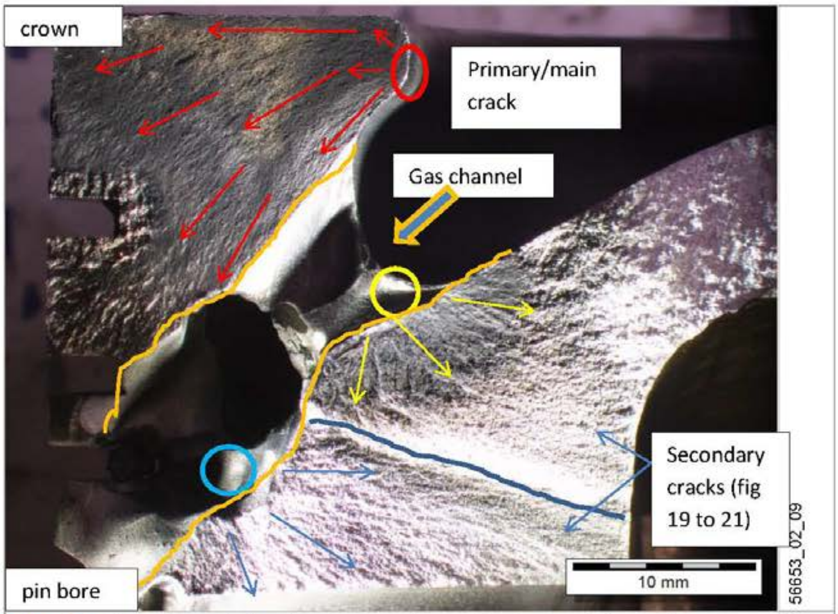



Fig. 15: Overview of the fracture surface, Fracture origin and –propagation are marked

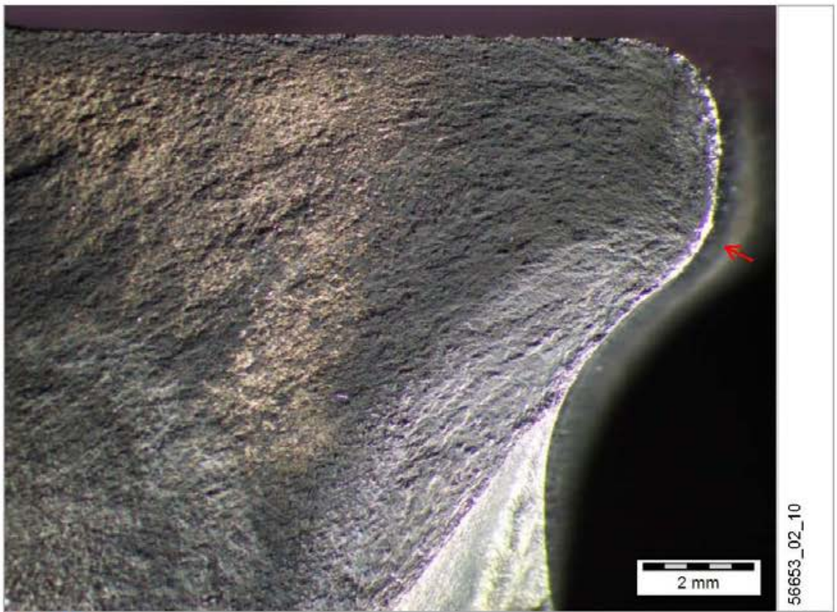



Fig. 16: Primary fracture induction site

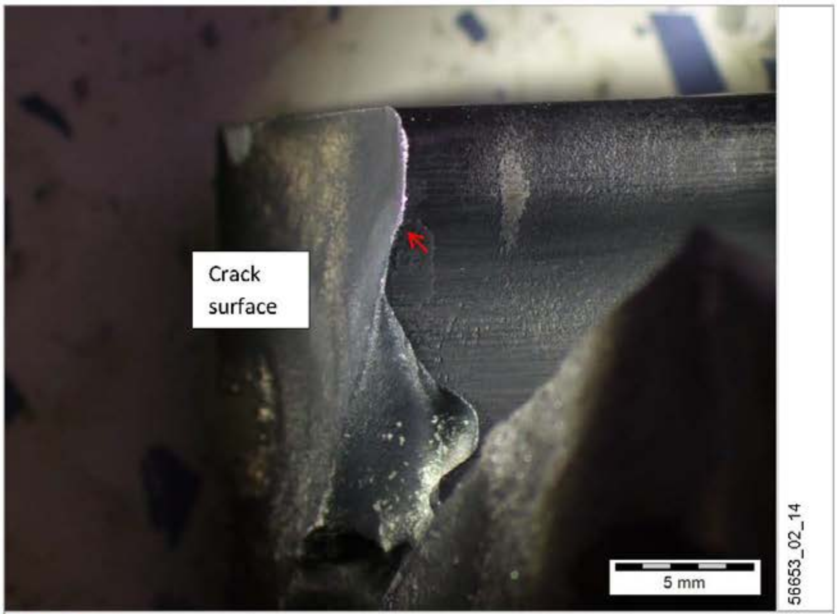



Fig. 17: Overview of the fracture induction, no mechanical defects detectable

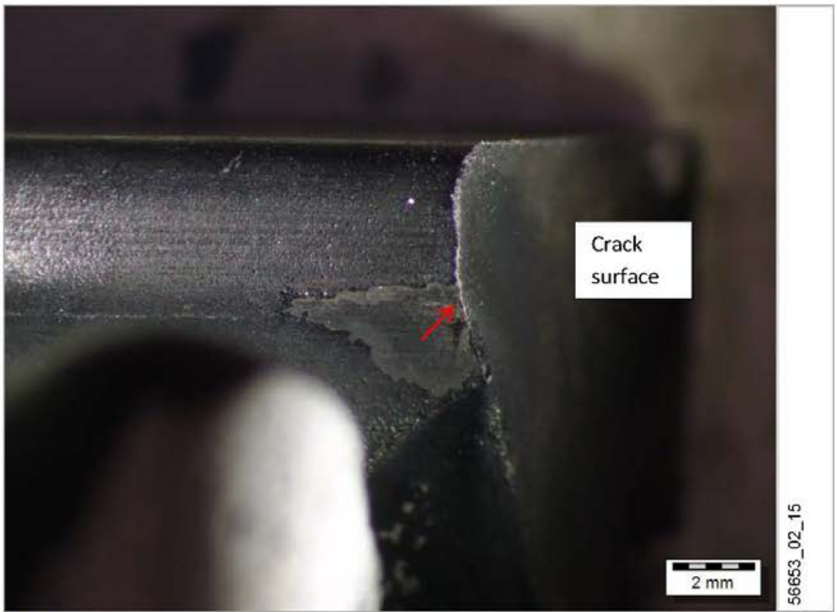



Fig. 18: Overview of the fracture induction, no mechanical defects detectable

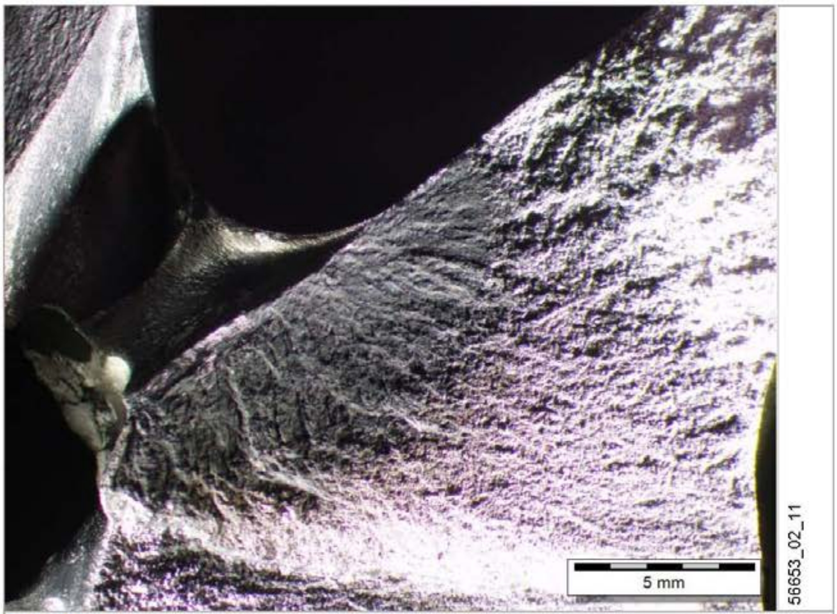



**Fig. 19:** Overview of the fracture induction next to the gas channel entrance

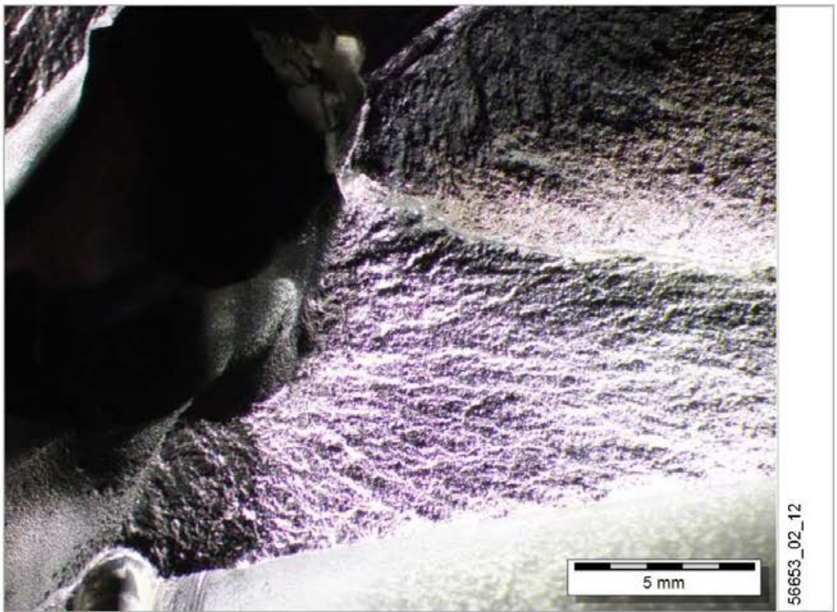



**Fig. 20:** Overview of the fracture induction at the gas channel above the piston pin bore

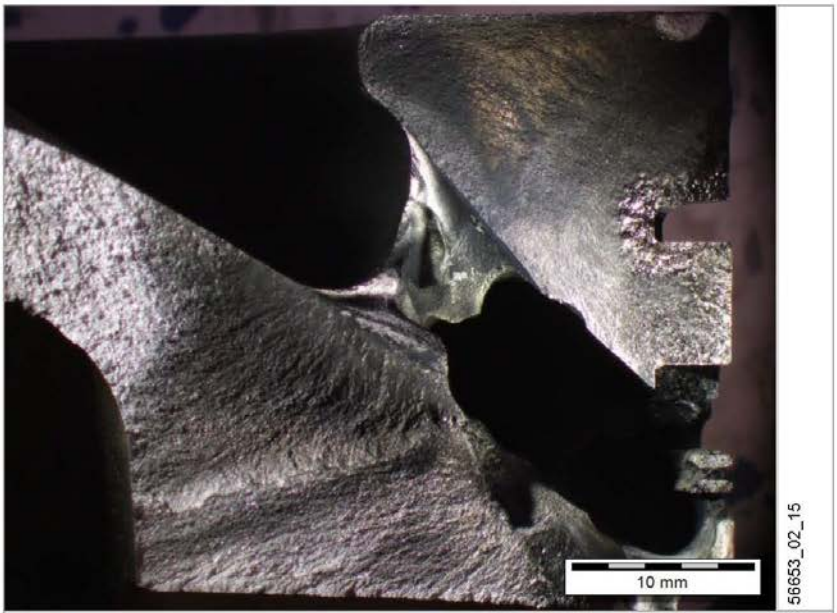



**Fig. 21:** Overview of the fracture surface (counter surface to fig.15)

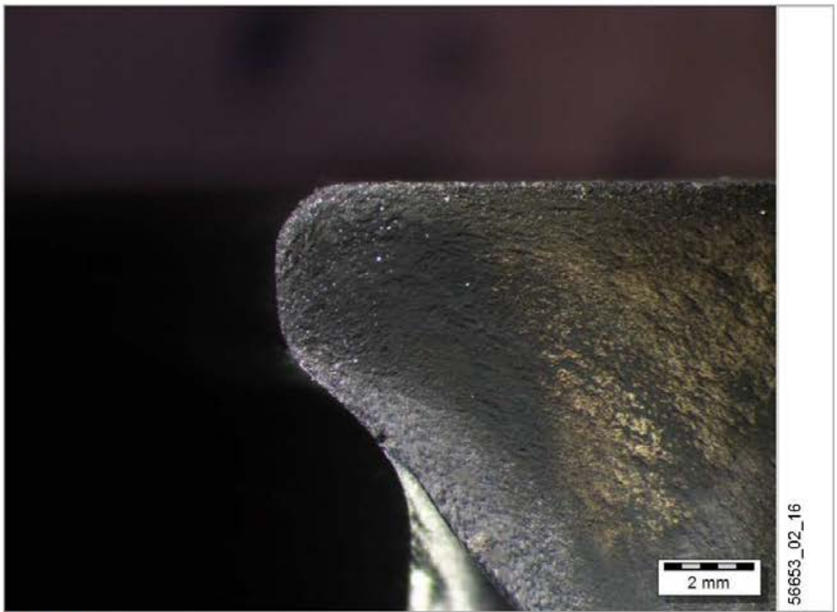
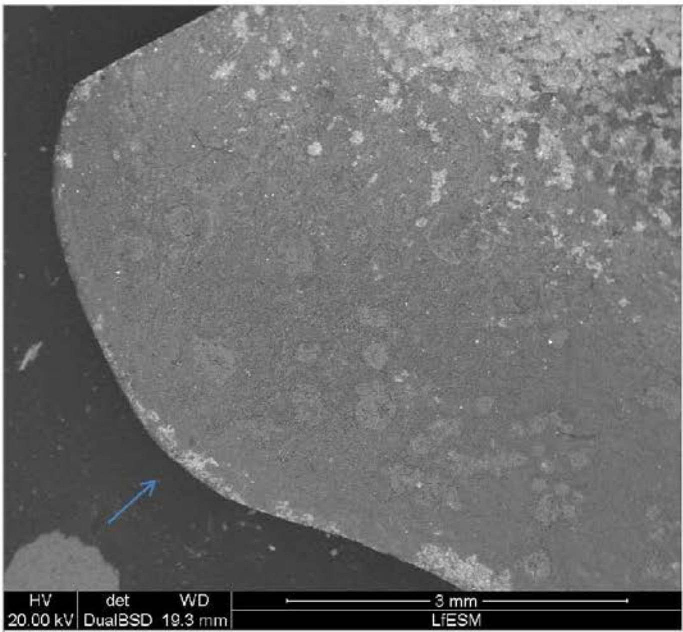
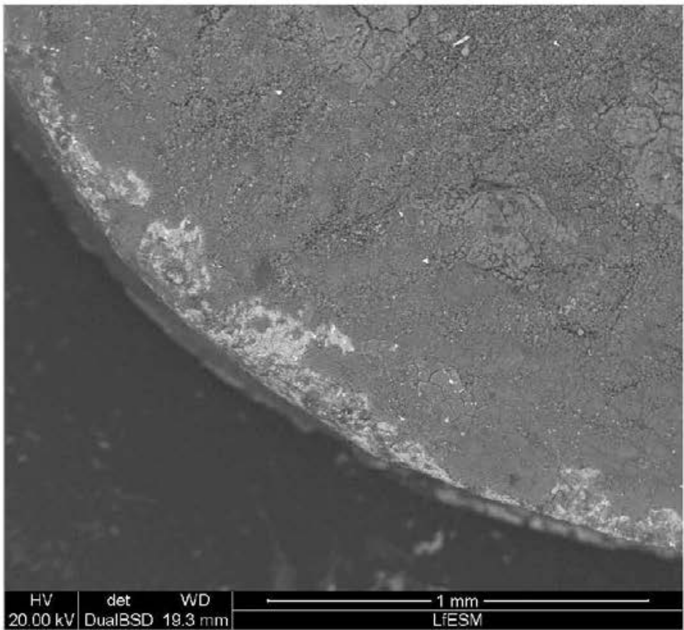



**Fig. 22:** Overview of the fracture induction at the crown (counter surface to fig.14)




56653_01_02

**Fig. 23:** SEM picture (unfortunately by ultra-sonic cleaning the layers could not be removed)




56653_01_02

**Fig. 24:** SEM-picture of the fracture origin without any mechanical damage

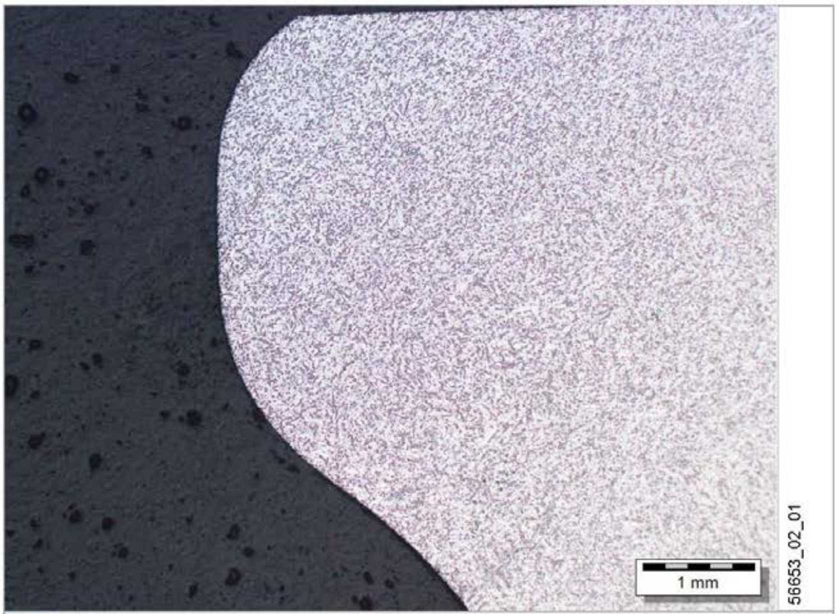



Fig. 25: Micro-structure next to the fracture origin

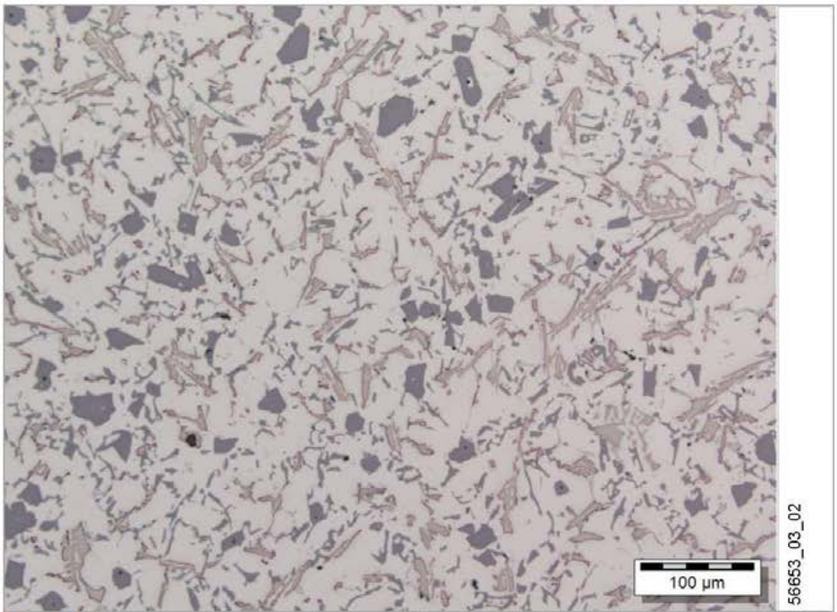
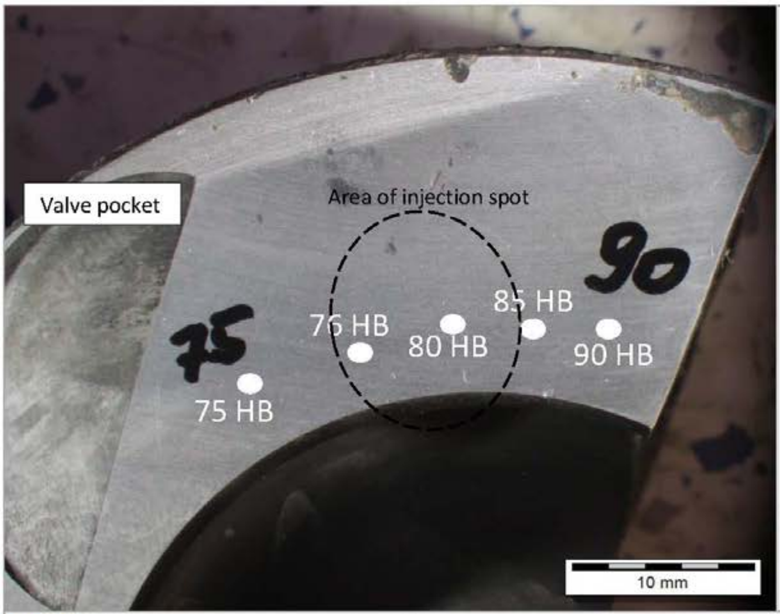
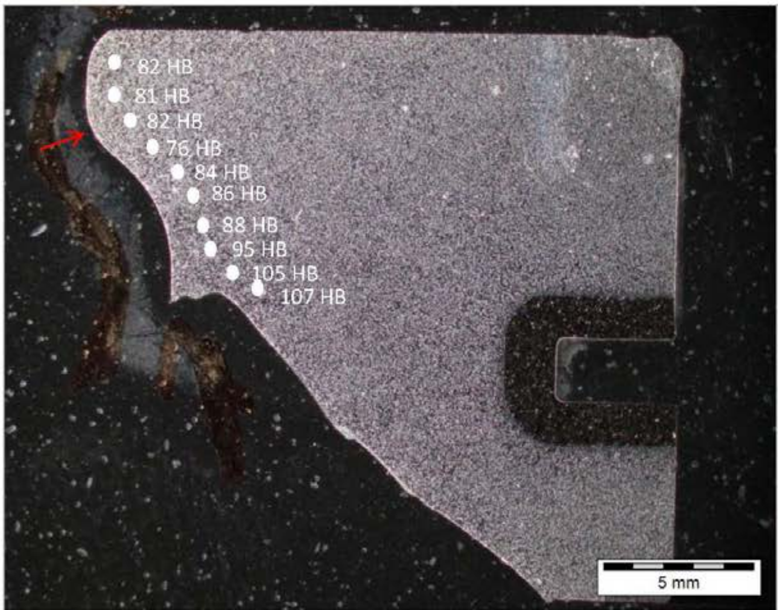



Fig. 26: Micro-structure




56653_02_20

Fig. 27: Hardness measurements at the crown next to the fracture origin; the surface has been ground for the hardness measurements. The hardness is increasing towards the fracture




56653_02_21

Fig. 28: Hardness measurements next to the fracture origin

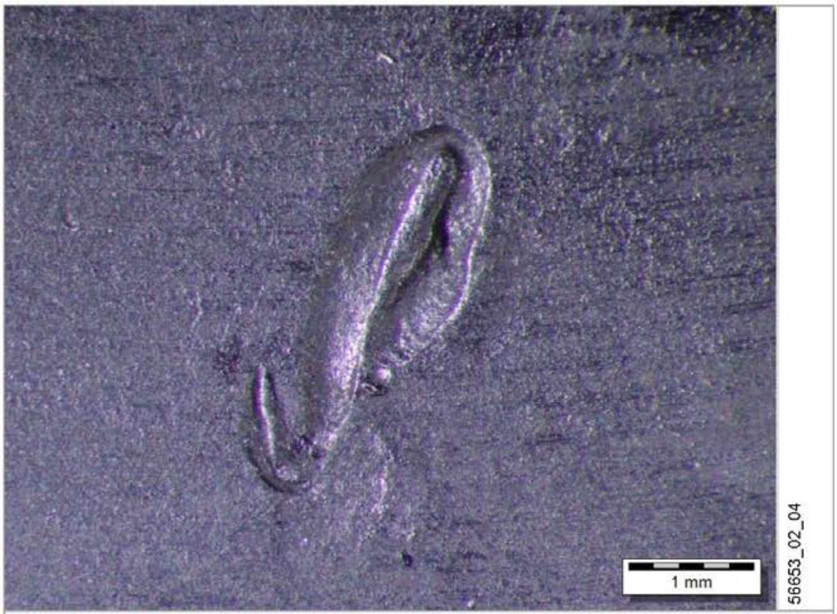



Fig. 29: Imprint of a foreign particle at the piston crown (see also fig. 8)

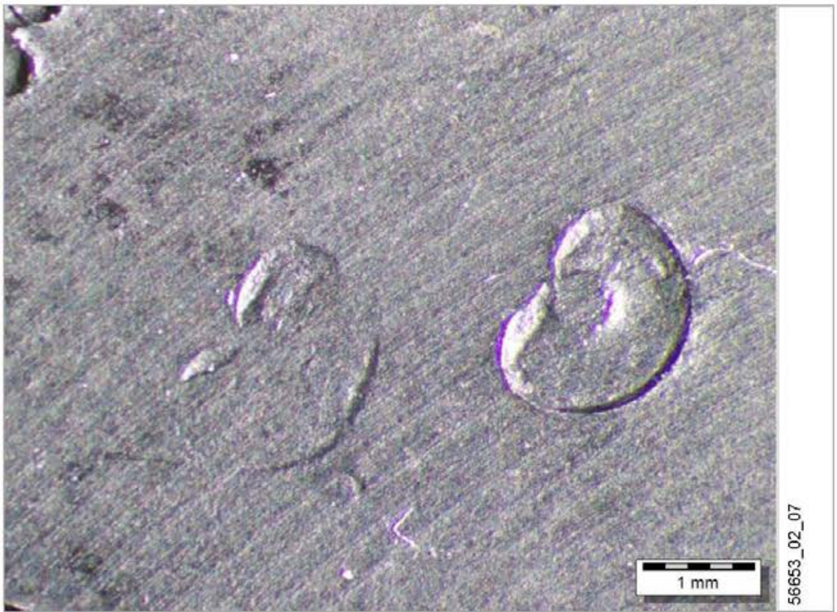



Fig. 30: Imprints of a foreign particle in the piston crown next to labelling (see also fig. 7)