Oil and gas related failures

Kamran David Fatehi and Sarah O’Loughlin, EXOVA Group Norway

⇒ INTRODUCTION

The oil and gas industry produces in the region of 1 billion barrels of petroleum per day with a current approximate price of $75 per barrel equating to around $75 billion production per day. When a failure occurs it can result in the shut-down of production of a platform at a cost of around $300,000 per day. Failure analysis and the prevention thereof is an important instrument in keeping oil and gas platforms operational and hence production costs to a minimum.

There are a number of extreme environments associated with the offshore industry, which can lead to a number of different modes of failure. Today I'm going to talk through examples of the main types of oil and gas related failures we see at Exova AS in Stavanger, Norway along with some interesting ones from associated manufacturing.

⇒ CORROSION ISSUES

Corrosion failures can be split into failures that occur on the rig itself, those associated with drilling and those associated with transportation of
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The produced fluid, as the environments associated with each is different. The failures that occur on the rig itself are usually associated with the sea environment; failures that are associated with drilling can occur due to the presence of chloride ions in the produced fluid / drilling mud or the presence of hydrogen sulphide in the produced fluid; failures associated with transportation of the produced fluid can be due to the presence of chloride ions in the produced fluid, added inhibitors or microbes.

⇒ Stress Corrosion Cracking

Stress corrosion cracking is by definition cracking that occurs under the joint influence of an applied stress and a corrosive environment and is often typified by branched cracking.

This is an austenitic stainless steel drill string which was non-destructively examined and cracks were seen to be present across the outer surface at the change in section. The cracks were seen to be branched and transgranular and the size, transgranular nature and orientation of the larger cracks suggested that stress was the predominant mechanism in crack growth, with stress being circumferential in direction.

⇒ Examination of the microstructure revealed the presence of sensitisation, grain growth and/or recrystallisation. Sensitisation is the process whereby chromium carbides form at the grain boundaries in austenitic stainless steels, leaving a chromium depleted region immediately surrounding the carbides. As austenitic stainless steels rely on chromium to provide their corrosion resistance, depleted regions leave the microstructure prone to localised attack. This occurs when the
steel is exposed to elevated temperatures for prolonged periods of time with grain growth and/or recrystallisation also seen at elevated temperatures, indicating that the pipe outer surface had been exposed to localised elevated temperatures.

Due to the environment the drill pipe operates in and the location, it was believed that the localised heating could be associated with friction. The corrosive media was not determined as only non-destructive testing was carried out.

**Localised Corrosion – chemical injection**

These sections are both similar parts, the larger pipe is the main pipeline with the smaller branch being used to enable an oil coagulant to be introduced to the produced water. Within the branch was a quill pipe through which the corrosive chemical was introduced, which extended into the centre of the spool. The quill pipe was manufactured from 316 stainless steel and it is thought that stress corrosion cracking of the quill pipe from the chlorides in the produced water led to expulsion of the chemical whilst still within the branch. The injected chemical is not believed to be corrosive once diluted in the produced water.

The operation of the quill is meant to disperse the chemical into the produced water stream. The chemical is a sulphate-iron based coagulant which forms a barium-sulphate scale when in contact with the produced water. The spool and branch assembly were manufactured from carbon steel.
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Examination of the spool on the left revealed that corrosion was isolated to within the branch, with accelerated corrosion of the weld material, which had led to a breach in the external surface within 10 weeks.

Examination of the spool on the right revealed that corrosion was concentrated around the branch mouth, with accelerated corrosion of the weld material, which had led to a breach in the external surface at the weld fusion line of the weldolet after 12 months in service.

In the case of the spool on the left; it is believed that cracking of the stainless steel quill pipe released undiluted chemicals into the branch. Due to the configuration of the branch, the produced water in this region would have been fairly stagnant. This would have allowed a build up of concentrated chemicals in this region resulting in a much faster time to leakage than seen on the other spool examined.

In the case of the spool on the right; it is believed that cracking of the stainless steel quill pipe released chemicals into the branch and spool. As the leak was in the branch mouth the flow of produced water would have diluted the chemical, reducing the speed of attack compared with the other spool examined.

Localised Corrosion – Microbially Influenced Corrosion

The presence and activities of microbes can influence the corrosion of metals by altering the rate and type of electrochemical reactions occurring at or near the metal's surface.
This carbon steel bend contained produced water at approximately 38°C. Examination of the bend revealed SRB influenced corrosion of the internal surface with accelerated corrosion in a confined region on the intrados of the bend. It is believed that this region of accelerated corrosion is due to its location – a low flow rate in this region could have led to a build up of debris which would have increase the anaerobic nature of the immediate environment. As SRBs thrive in anaerobic conditions they would have produced more sulphides and hence driven the corrosion rate.

**Localised Corrosion – Pitting**

This carbon steel pipe was a section of 1” piping used for metering of oil properties and a hole in the pipe had led to leakage of the oil. In service the pipe was horizontal and the hole was located at the 4 o’clock position. There was continuous flow through the pipe, with the operation temperature being 57°C at a pressure of 26bar.

Bacterial problems had been experienced in the produced water system on this platform, so this was a concern with regards to the corrosion in this pipe section, although the water cut was less than 2%.

Onsite X-ray examination showed evidence of further pitting in the pipe containing the leak.

There was a thick black deposit observed inside the bore of the pipe and upon sectioning liquid was observed escaping from between the deposit and the internal pipe surface. Analysis of the deposit showed it was a waxy deposit thought to have formed due to deposition from the
fluid passing through the pipe. A second deposit was found in the region of pitting, adjacent to the pipe surface and this was seen to contain iron, chlorine and oxygen typical of seawater corrosion.

It is believed that these pits were occluded and fluid found beneath the deposit showed that the moisture in this region had been maintained allowing pitting to progress and breach the external wall.

⇒ Localised Corrosion – Preferential Attack

This is a 2” pitted pipe section manufactured from 25%Cr super duplex material. The pipe is part of a system that transports produced water containing a few ppb of oxygen, with a heat trace of approximately 120°C. In the region of pitting the contents consist of a humid gas phase containing approximately 2.5% CO₂ and 30ppm H₂S, with 8% NaCl present in the water phase. The condensed water in this region is believed to be approximately pH 4-5.

Examination of the leak revealed a large pit present within the wall thickness. Pitting was also present at other locations around the pipe in the vicinity of the weld.

It is thought that grinding of the internal surface as part of the weld preparation led to an alteration of the local pitting resistance and this combined with condensed chlorine salts led to preferential attack of the ferrite phase. Pitting progressed through thickness until the outer surface was breached in the region of the leak.
Washout is a problem specific to the oil and gas industry and occurs when the high velocity produced fluid exits through a small opening. The force along with any debris entrained within the fluid leads to widening of the opening. Obviously, if the opening is a crack or a pit, this opening removes any detail of the failure mechanism.

Washout – threaded tool joint

This is a martensitic stainless steel tool joint which had cracked and leaked then suffered from subsequent washout. Microstructural examination revealed the presence of secondary hydrogen stress cracks in the martensitic microstructure. Further microstructural examination showed that the hydrogen cracks were present in a localised area, which could be due to the presence of a stress concentration.

Chemical analysis and mechanical testing produced results typical of a high-strength steel. High strength steels are particularly susceptible to hydrogen stress cracking and are not normally recommended when hydrogen may be present in the surrounding environment.

Charpy impact test results achieved were lower than those stated on the material certificate and this is thought to be due to the presence of hydrogen at the grain boundaries, causing weakness in the material.
Washout – Tube Section

This tube had leaked and suffered “wash-out” through a circumferentially elongated hole. Microstructural examination revealed the presence of a fine transgranular crack in the martensitic microstructure. The crack was widened by corrosion and had secondary cracking suggesting that the mechanism was corrosion fatigue.

It is believed that failure started from cracking at the outer surface and progressed through thickness due to corrosion fatigue. After cracking it was widened and enlarged by washout erosion.

In these particular cases the presence of secondary cracking allowed insight into the probable cause of failure but this is not always the case.

Equipment

There are numerous failures we see in different types of equipment used in or associated with the oil and gas industry, these are just a few examples.

Equipment – Drill String

This is a carbon steel drill string, which is a column of drill pipe with attached tool joints that transmits fluid and rotational power to the drill collars and the bit. Examination of the fracture surfaces revealed the
presence of two different fatigue cracks. The first crack had multiple initiation points along the internal surface with the crack perpendicular to the outer surface. The second crack initiated at a region on the outer surface and lay at an approximately 45° angle.

It is thought that the second crack occurred after the first due to the configuration of the fracture surface and may have only initiated due to a loss of cross-sectional area at this point due to the presence of the first crack.

⇒Equipment – Buoy Pipe

The pipe within this buoy assembly had fractured after being in service for approximately 3 to 4 years in a North Sea environment and had lost its top plate in use. It was suspected that the fracture had occurred during bad weather at sea.

Examination of the fractured buoy pipe assembly showed that it had failed at a fusion line of the weld between the pipe and top plate. Fracture appeared to have developed from multiple initiations around the whole circumference of the pipe and progressed through thickness until the remaining section could no longer support the applied load and final fracture occurred.

⇒Equipment – Drill Bit

This is a drill bit which is attached to the end of the drill string assembly and is used for the actual drilling. The drill had only seen 50 drilling
hours when it was noticed that the teeth were showing severe wear or damage.

Microscopic examination identified that fracture occurred in the polycrystalline diamond layer of the drill bit. It is believed that the most likely scenario is that the drill bits saw excessive temperatures (above 700°C) causing degradation to the polycrystalline diamond or matrix or both.

ASSOCIATED MANUFACTURING

Associated Manufacturing – Lifting Eye

This failure is of a lifting eye, which was welded to the top of a section of a shipping hull that was being assembled in a shipyard. Four lifting lugs had been welded to part of the shipping hull to enable easy transport and location of the part during assembly.

The lifting lugs were mounted perpendicular to the deck but after receipt by the client they were seen to have aligned with the direction of the hook and wire of the cranes at approximately 45°, so they were heated and straightened out by the client.

Subsequent fracture of one of the lifting lugs occurred suddenly and MPI examination of the three remaining lifting lugs showed cracking on two of the lugs, in a similar position to that of the fracture.
Examination of the fractured lifting lug and one of the cracked lifting lugs showed that the fracture and the crack were present in the same location. Both cracks were present in the plate heat affected zone of the weld and in the weld material between the plate and one of the rings.

A discoloured region on the fracture face, as well as oxidation of the crack, indicated that initial cracking of both lugs occurred prior to heating by the client. Therefore it can be concluded that initial cracking occurred either during initial bending of the lifting lugs or during original assembly.

The presence of the cracks would have reduced the cross-sectional area of the lifting lugs and hence their strength at this point. Final fracture occurred by brittle overload when the lifting lugs were used to carry the hull and could no longer support the applied load.

**Associated Manufacture – Cyclone**

This is a stellite liner used as a cyclone to separate oil from produced water, with the fracture occurring in the weld region between two cast sections of the liner.

Examination of the weld profile revealed that the weld did not encompass the entire joint but was off to one side. The minimal amount of material holding the joint together is not believed to have been able to support the applied load, which could have been much lower than the design load.
Associated Manufacture – Welded Elbow Section

Cracking had been observed during routine, post-fabrication, dye penetrant inspection. Two days had passed between fabrication and dye penetrant inspection with the pipe and elbow assembly kept in an environmentally controlled area. The parts of the pipe and elbow assembly were 316L stainless steel.

After examination of the outer surface of the weld revealed no obvious regions of cracking, longitudinal sectioning to allow examination of the internal surface revealed the presence of three regions of cracking. The three regions were approximately 120° apart with the cracks emanating perpendicularly to the weld.

Microscopic examination showed that the cracking was present within the parent material and subsequently progressed into the weld material.

The cracks were seen to be intergranular and grain boundary carbides were present along the grain boundaries in these regions. Due to the lack of corrosive agent it is thought that the most probable cause of failure is by these carbides reducing the strength at the grain boundaries, with cracking occurring due to the stresses applied by the material during cooling.

The specific and isolated location of these regions of cracking and carbide formation were discussed with the client and it was determined that prior to welding it is common practice for the welders to place spot welds at 120° around the circumference of the joint. It is believed that carbon steel weld material was used to produce these spot welds.
erroneously and upon heating the carbon migrated along the grain boundaries forming the carbides observed.

\[\textbf{⇒Associated Manufacture – Pipeline Section}\]

This pipe section had been in service when NDT revealed the presence of a pit. Examination revealed that the pit was cone shaped, with the presence of a heat-affected zone along the outer surfaces and a region of melted material plugging the external surface. Initial thoughts were that it was a region of weld material that had corroded away but there was no evidence of further weld material in the immediate vicinity of this pit. Further thought and evaluation showed that the pit coincided with one side of the weldolet located 180° around the pipe from it. It is believed that this weldolet was an in-service addition and that a section of pipe was flame cut out to accommodate the weldolet. It is thought that the initial burn through to start the removal of the section occurred opposite the ‘pit’ and that the pit actually was loss of melted material by excessive flame size / heat.