DOI : https://doi.org/10.56452/2023-04/007

ISSN: 0974-5823 Vol. 8 No. 4 April, 2023

International Journal of Mechanical Engineering

Failure analysis of drill tools in petroleum industry

MOHAMMAD .N ALRAKAF

Trainer : Public Authority for Applied Education and Training- Kuwait

Abstract

One of the main causes of the high expenses connected with drilling oil wells in the oil and gas business is the lack of understanding of drillstring and component failure analyses, which includes the drill collar and the drilling bit. The price of the product is extremely expensive as a result of this underlying mistake. To accelerate penetration, lower drilling costs per foot, and reduce well deviation, it is common practice to use a variety of drilling technologies, including air drilling, percussion drilling, and downhole hydraulic ultra-high pressure jet-assisted drilling. The pace of penetration can be accelerated, the cost of drilling per foot can be decreased, and the quantity of well deviation can be kept to a minimum. The best method to complete what has to be done is to combine these several approaches. However, as a result of these drilling operations, the materials utilized to make the parts of downhole drilling equipment are subjected to much more difficult working conditions. Because the characteristics of the instruments are inadequate to meet the demands of working in such circumstances, the chance of the drillstring breaking is raised as a result. There may be a substantial quantity of bit bouncing and severe vibration if the geological conditions are adverse and the process of breaking up the rock requires a significant number of strikes. Realistic failure modes for drilling equipment include tooth loss, fracture, wear, and microcracks. Another possible reason for failure is drill pipe fatigue, which is brought on by the bending force produced by buckling stress. It was discovered that numerous failure mechanisms were brought on by the teeth. The findings of this study provide a thorough examination of the elements that lead to poorly performing drill sections and wells. When this is done, risks have a greater chance of being effectively handled, and the aforementioned areas could experience peak performance. Operational factors like bottom hole temperature and solid content are looked at when it comes to the longevity of drilling equipment. The impact that predrills projections of pore pressure or wellbore stability have on the drilling procedure is also examined.

DOI : https://doi.org/10.56452/2023-04/007

Introduction

Due to increased drilling depth, the development of high-angle wells, and the introduction of big displacement horizontal wells, the requirements for the performance of drill stems have become noticeably more demanding in recent years. Every drilling rig used for the production of oil and gas needs drill stems to function properly. In the case that a drill stem malfunctioned or was engaged in an accident during the process of oil and gas exploration, a sizeable sum of money may be lost. For several reasons, including the improvement of drill stem management standards, the creation of a comprehensive drill stem monitoring, evaluation, and inquiry system, the assurance of drill stem quality and drill string safety, and the reduction of drilling costs, research on tool fatigue prediction is crucial.

The method known as "well drilling" is the one that the petroleum industry views as being the most important when it comes to obtaining oil and gas. The phrase "drilling rig" refers to the piece of large machinery that is employed when drilling into the ground's subsurface. A "rig" is the term used in the industry to describe the intricate apparatus required to penetrate the earth's crust. The bottom of a drilling rig is made up of three parts, according to Macdonald and Bjune (2007): the drill pipe, the transition pipe, and the bottom hole assembly. The drilling rig's bottom is made up of these three elements. The hollow bottom portion of the drill is referred to as the "drillstring." Both the drill bit and the rock-breaking drill collar are already placed in the bottom hole assembly. The hefty bottom hole assembly includes a hollow tube with thick walls. Drilling fluid is pushed up and down the annulus by this tube. The annulus is the area that separates the drillstring from the casing. Drill collars are transferred from drill collars to drill pipe using the second component, a sizable drill pipe. This part is utilized throughout the drilling operation. This increases the weight of the drill bit while also lowering the occurrence of fatigue failures above the bottom hole assembly. The drill pipes are in charge of getting the drillstring to the surface completely. Tool joints, which are longer tubular components than the remainder of the pipe, are used to manufacture drill pipes. These tool joints contain female "box" connectors on one end and male "pin" threaded connections for joining segments. The diameter of each drill pipe segment is the same, but the top is constructed of a material with greater strength to hold the drillstring and withstand greater axial forces. The additional axial loading won't have a detrimental effect on the drill pipe's performance. Fang and Duan (2014) conducted a thorough analysis of how drilling quality and rate have influenced the expansion of oil and gas reserves. They provide further details in their paper. The costs associated with drilling oil and gas wells were thoroughly examined by Lukawski et al. (2014). They also talked about the many varieties of drilling platforms and their operating features.

In addition to lowering well placement azimuth and depth uncertainty, using drilling fluid that is aligned with the drillstring improves penetration at a lower cost, creates favorable borehole conditions, and has a high drilling efficiency in wells and borehole sections. The use of drilling fluid that is aligned with the drillstring may be responsible for these advantages. These methods are also used to increase penetration rate while reducing total costs and preserving optimal borehole conditions. In contrast to the more traditional technique of mud drilling, percussion drilling, according to Fan, Huang, Gao, and Li (2011), is able to greatly enhance the pace of penetration while simultaneously lowering the risk of well deviation and formation damage. As a direct result of this, the gas and oil sector has found extensive usage for this approach. This has directly contributed to the rise in the popularity of percussion drilling in recent years. The use of air drilling technology has also been shown to have the ability to considerably speed up penetration (Wang, Zang, Zhang, Bu, and Li, 2011).

By placing a hydraulic ultra-high pressure jet assisted downhole driller immediately above the drill bit and pressurizing the drilling fluid to generate an ultra-high pressure jet flow for rock cutting and breaking, it is feasible to significantly speed up penetration. This has directly

caused the drilling pace to increase, which has caused an acceleration. Liao, Guan, Shi, and Liu (2015) assert that this tactic also utilizes cutting and cleaning procedures.
But each of the aforementioned drilling techniques has a unique set of limitations that, when paired with the difficult operating circumstances, might pose a serious risk to the drillstring's ability to stay safe. In percussion drilling, for instance, the bit is spun such that its teeth are in constant contact with distinct rock formations. To get as much material out of the rock as possible, this is done. This is done in an effort to collect as much rock as is physically possible. Significant drilling tool failures, according to Fan, Huang, Gao, and Li (2011), have hindered industry growth. After doing their investigation, they came to this conclusion. The loss of teeth, the fracture or wear of teeth, and the wear of teeth are only a few examples of how these failures might show themselves. According to Patil and Teodoriu (2013), it is conceivable to drill a high-quality well at a cheaper cost per foot and in the lowest amount of time by combining a drillstring with percussion or air drilling. One way to achieve this aim is by using a drillstring. However, adopting this type of drilling has the potential to result in a number of barriers that limit the drilling's effectiveness, such as vibrations produced by the drilling. The effectiveness of the drilling may be hampered by these difficulties. Drilling fluids, such as water-based fluid muds, are used to drill boreholes in order to lubricate the drill bit, clean the hole's bottom, and bring cuttings to the hole's top. Drilling fluids are also utilized to clean the hole's bottom. Drilling fluids are also utilized to clean the hole's bottom of any dirt and debris. On the other hand, this fluid may contain a number of substances that are potentially harmful or will result in corrosion. These substances can include dissolved synthetic chemical compounds (such alkalies, salts, and surfactants), a variety of insoluble materials (including barite and clay), organic polymers in a colloidal state, as well as emulsified oil. These chemicals may also contain a number of other components. As a result, a thorough examination of the events that led to the failure of drilling instruments when they were being utilized in actual drilling operations is necessary. In particular, it is critical to look into the factors that contributed to the failure of drilling equipment. Therefore, the main goal of this literature review is to investigate the possible failure mechanisms in drilling instruments as a result of cutting operations that take place in oilfields.

Scope of the research

This study's main goal is to thoroughly investigate all of the failures and causes that have been seen in drilling instruments (such as drillstrings and drill bits) when they have been used in the drilling process for oilfields. Learn the foundations of drilling, including how it is done, what makes up a drillstring's most important parts, and how drilling aids may be used to increase productivity. Additionally, it clarifies the primary causes of various failure modes in wells and borehole sections, which is crucial for risk reduction and maximizing performance potential. This article also discusses the role that operational factors, such as bottom hole temperature and solid content, have in determining the amount of time that drilling instruments can operate efficiently. These topics include pre-drill estimates of pore pressure or wellbore stability.

Failure analysis of drilling tools

The drillstring experiences a range of steady forces during oilfield downhole drilling, including tension, compression, bending, and twisting. This is particularly true when drilling into strata in areas with a mix of straightforward and complex geological conditions as well as ecosystems created by continental deposition. As a result, drilling equipment is breaking down, penetration rates are dropping, it takes longer to fix broken instruments, and borehole conditions are getting worse. All of these things cause a slowdown in the growth of the oil and gas industry. Several studies have been conducted to get a deeper knowledge of the components that lead to this kind of failure and to pinpoint the conditions that enable the most productive work to be done downhole in an effort to reduce the number of accidents brought on by drillstring failure. The next sections will discuss the study of failure for various drillstring segments. This examination considers the facts of the incident as well as any potential contributing factors.

A. Failure analysis of the drill pipe

Failure of the drill pipe is the downhole might be caused by a complete break in the drill pipe or by a broken component of the bottom hole assembly. The failure of the drill pipe might occur for one of these reasons. Due to the challenging geological conditions in which ultra-deep well drilling occurs, drill pipe failure is a frequent occurrence. This section will examine a number of typical drillstring failures with a focus on the many types of drill pipe failure that have been compiled from prior studies.

A1. Fatigue

Most drill pipe failures are due to fatigue. It is possible for the surface drilling hook or bit to become worn out when it is subjected to stresses ranging from 0 to 3000 kN and rotating speeds ranging from 50 to 200 rpm. According to Macdonald and Bjune (2007), the speed of drilling equipment may range anywhere from one meter to fifty meters per hour, while the torque that is exerted on the drillstring at the surface by borehole friction can range anywhere from half a kilonewton to seventy kilonewton meters. Both of these figures can be found in the table below. Figure 1 illustrates what researchers Lin, Qi, Zhu, Zeng, Zhu, Deng, and Shi (2013) as well as Knight and Brennan (1999) have shown to be the cause of drilling tool failure: a concentration of stress in the thread roots connections and the upset transition area of the drill pipe.

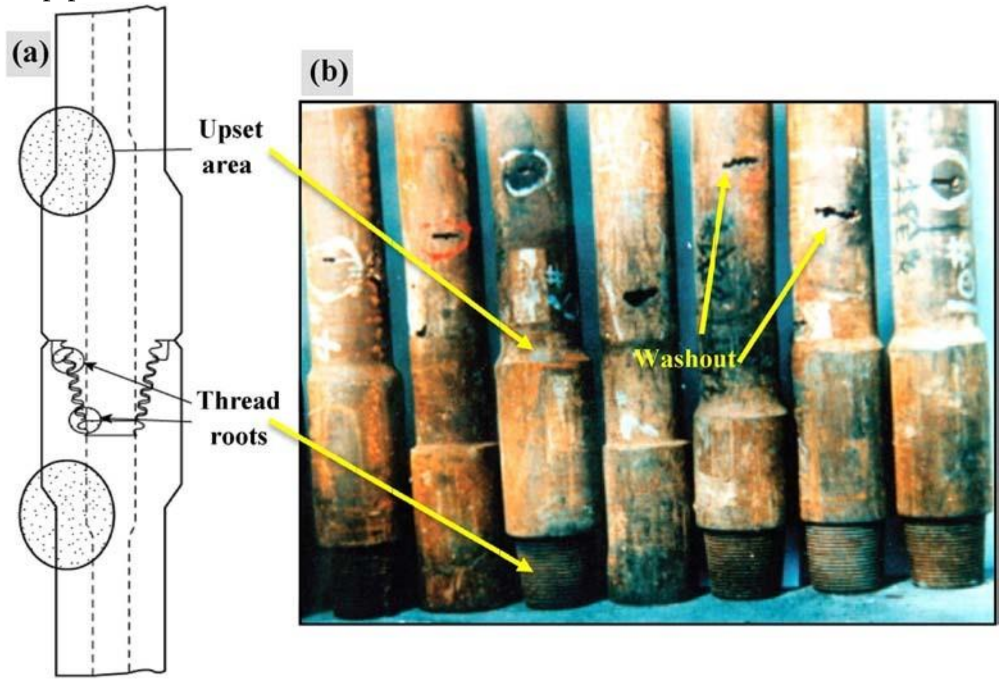

Figure (1): Failure owing to washout in the drill pipe transition zone (Fangpo & Xin, 2011) and failure due to fatigue in crucial areas of the drill pipe and connection (Macdonald & Bjune, 2007).

Knight and Brennan (1999) investigated the impact of drill collar bore eccentricity on the fatigue life of the drill bit. They discovered that, in addition to a little degree of eccentricity, any stress concentration in the drill collar bore might potentially reduce the drill pipe's ability to withstand fatigue under bending stresses. No matter how mild or extreme the eccentricity, this was always the case. Lin et al. (2013) modeled the mechanical characteristics of the drill pipe upset transition region using the ANSYS program. Their objective was to increase the drill pipe upset transition's efficiency in terms of both its size and its use. They were able to determine the proper dimensions for the drill pipe upset transition as a result. Fangpo and Xin (2011) did a simulation to determine the stress status in the drill pipe transition zone. They found that the transition zone was the drill pipe's weakest area and that the amount of stress that was concentrated there depended on the pipe's length and chamfer radius R. They also discovered that the amount of stress focused there depended on the pipe's length and chamfer radius R.

The drillstring may experience fatigue loadings such as dog legs, which is a reversal of bending brought on by borehole characteristics, and a plethora of sources accumulated under dynamic vibration (Macdonald & Bjune, 2007). If the drill pipe rotates over a curved section of the hole while drilling a horizontal well, the wellbore may produce dog legs. There are several wellbore locations that are prone to inescapable aberrations, as shown in Figure (2). The lack of homogeneity in certain areas can be used to identify them. The stresses that are produced (cycles) fluctuate between states of tension and compression as a direct result of the material's kinks.

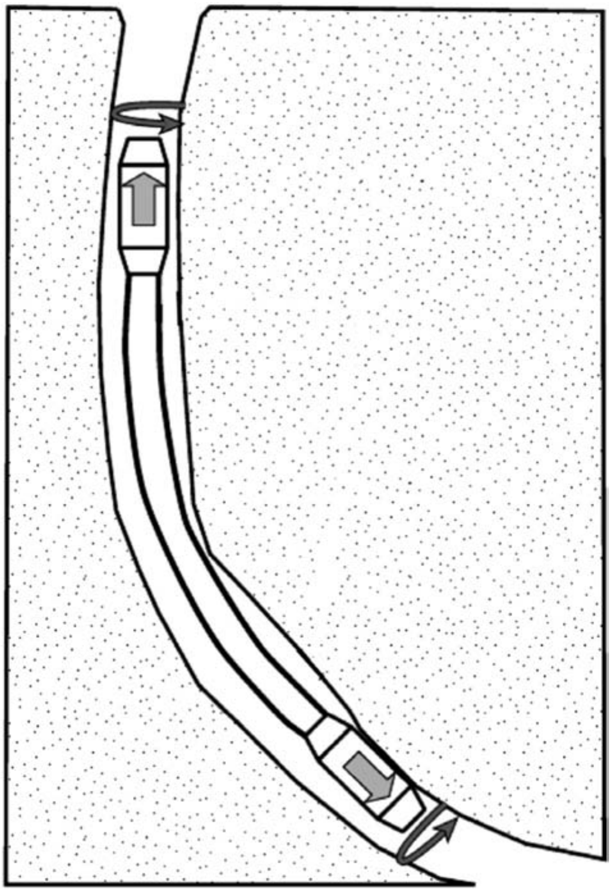

Figure (2) (Macdonald & Bjune, 2007) depicts loading being imparted to a drillstring as it passes through a dogleg.

The efficiency of beveled shoulder threads while using the horizontal directional drilling technique was studied by Zhu et al. (2016). Beveled shoulder threads were found to be particularly useful for making drill pipe threads because of their high bending strength, considerable flexural stiffness, and ability to tolerate substantial bending loads. As a result, drill pipe threads might be manufactured using beveled shoulder threads.

Luo and Wu (2013) investigated the effect of stress concentration on the failure of the pin and box threaded connection of the upset drill pipes under combined tensile and bending stresses. The joint was flexed and put under tension while performing this motion. A fatigue fracture that started at the beginning root of the teeth of the pin tool joint shoulder of the drill pipe caused the tool to break. The fracture also started here since here is where the stress concentration was the greatest. The tool was unsuccessful because the crack completely through the joint wall. The fatigue resistance of the tool joint starts to deteriorate at the dogleg area due to the high cyclic bending stresses that are present there. The local inclination of the drill pipe away from vertical is what causes these stresses.

Wang et al. (2011) gathered a sizable number of complaints of issues with drillstrings in the northern Sichuan province. It has been reported that either the drillstring's poor quality or the presence of manufacturing flaws in the drillstring itself can have a detrimental impact on the process of preserving the drillstring's strength. Additionally, it has been noted that if the drillstring was created incorrectly or in a non-scientific manner, it can have a negative impact on the process. The drillstring's early failure was probably caused by the strains brought on by the faults' unequal propagation and distribution. In addition, it was found that drillstring sticking and inadequate anti-sticking techniques, including excessive pushing and pulling, caused the fatigue failure of the drillstring shown in Figure (3). The failure was caused by these elements. The excessively high compressive or tensile stress that was then acting on the drillstring is what caused this failure. As observed in Figure (3), the high tensile or compressive stress that led to the drillstring's fatigue failure was likely the cause.

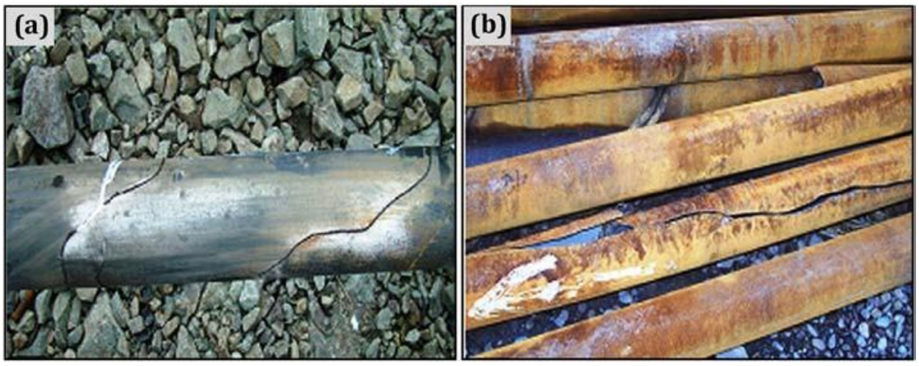

Figure (3): Gas drilling caused two types of fractures: (a) one caused by fatigue, and (b) one of the drillstring caused by hydrogen embrittlement (Wang et al., 2011).

A2. Vibration

The drillstring is subjected to high and complex dynamic loadings from the surface spinning of the rotary top drive. This turbulent flow downhole and wide range of pressures might lead to the drillstring breaking too soon. The rotary top drive may cause this kind of failure. A physical manifestation of the drillstring's oscillatory properties is vibration, which is also referred to as the drillstring's back-and-forth motion. The use of drilling aids, such as air drilling, which may worsen drillstring vibration by impeding the dampening effect that the drilling fluid provides, is another plausible cause, according to Wang et al. (2011).

Axial, torsional, and lateral vibrations in all three dimensions are all possible using drillstrings. Axial vibration along the drillstring's length may be sensed as it spins. Both lateral and torsional vibrations occur when the drillstring advances laterally toward its axis while spinning unevenly from the surface at a constant speed. The drillstring spinning is what causes both kinds of vibration.

The likelihood of the drillstring vibrating concurrently in all three fundamental modes is higher than the likelihood of it vibrating in any one mode on its own. Drilling will be less effective as a result, and the drillstring will vibrate in an unpleasant manner. Therefore, it comes down to operating the drillstring at a speed that is either above or below the critical speed, in addition to performing pre-drilling analysis and real-time analysis of the dynamics of the drillstring (Sahebkar, Ghazavi, Khadem, & Ghayesh, 2011). This will lessen vibrations and the likelihood of an early failure of the downhole.

According to Ghasemloonia et al. (2014), they correctly predicted that vibration modes that change with the altering of drilling parameters like rotary speed and weigh-on-bit will impact the design of the bottom-hole assembly. We qualitatively evaluated and demonstrated the impacts of axial stress spatial variation, driving torque, and mud damping on the process. Additionally, research was done on the drillstring's nonlinearities caused by its shape, axial stiffness, strain energy, and Hertzian contact forces. It was found that the damage suffered by the drilling machinery as well as by the drillstring as a whole was caused by coupled nonlinear axial-transverse vibrations as well as lateral instabilities. When Kapitaniak et al. (2015) assessed the impact of stick-slip oscillations, whirling, drill-bit bounce, and helical buckling of the drillstring on the conditions of the drilling rig, whirling was shown to be the most important contributor.

In recent years, Butt's team has written many publications (Ghasemloonia et al., 2015) that offer a thorough overview of drillstring vibration modeling. These articles can be useful for understanding the effects that developments in "Measurement While Drilling" tools and their real-time implementation have had on drillstring vibration modeling and the state-of-the-art of axial, torsional The goal was to find a technique that may limit the potentially catastrophic damage to the drillstring and delay the event that was unavoidably going to occur. A computer model created to predict the strains caused by axial and torsional vibrations came to the conclusion that drilling performance was substantially hampered and the drill string's lifespan was drastically reduced. This was discovered through a review of the modeled outcomes.

Numerous academics have acknowledged the presence of nonlinear stochastic dynamics such as bit-bounce, stick-slip, and transverse effects (Kreuzer & Steidl, 2012; Agostini & Nicoletti, 2014; Tang & Zhu, 2015; Xue et al., 2016). To make sure that the drilling procedure would run as smoothly as possible, this was done. In order to understand how changing the direction that dynamic traveling waves traveled affected the torsional vibrations, also known as stick-slip vibrations, that occurred in the drillstring, Kreuzer and Steidl (2012) conducted the study. In addition to moving upward toward the top drive, the waves also traveled downward toward the drill bit. Stick-slip vibrations have been found to be harmful to drilling because they delay penetration rates and may eventually result in the failure of the drilling operation. Research on the impact of lateral vibrations on the bottom hole assembly was done by Agostini and Nicoletti (2014) during the back reaming operations, commonly known as the process of removing the drillstring. When anomalous lateral vibrations take place during back reaming, it has been proven that the electronic machinery that controls the bottom hole assembly would malfunction. This may lead to the assembly collapsing, foreign objects entering the hole, and the drillstring becoming obstructed. According to Tang and Zhu's (2015) block-on-belt model analytical findings, stick-slip vibration on a drillstring length of 3000 m is bad for both the drilling machinery and the efficiency of the drilling procedure.

In order to analyze the vibrations of the drillstring in relation to the effective length of the string when it is resting on the borehole wall as well as the precise shape of the beam curvature, Hakimi and Moradi (2010) used the differential quadrature technique. This was done in order to comprehend the drillstring vibrations better. This was done in order to better understand how these two features are related to one another. The assignment was accomplished since it was necessary to do it in order to determine the exact outlines of the curved beam. The results of the numerical study show that when the length of the string and the beam curvature are taken into account, both the axial and torsional natural frequencies are adversely affected. As a result, the effectiveness of the drilling procedure and the precision of the data it yields are adversely affected. Additionally, it was demonstrated that the natural frequencies were unaffected by the string's length in any way.

A3. Buckling

In the oil and gas drilling industry, determining the weight that causes drill pipes to buckle has proven to be a challenging issue. This is because, according to Hajianmaleki and Daily (2014), the buckling load has the ability to increase the bending stress, which can ultimately result in the drill pipe's fatigue failure. This is due to the possibility that the buckling load may increase the bending tension. This is the major cause of what happens. (Hajianmaleki & Daily, 2014) discusses the bulk of the analytical, computational, and experimental research that was done to look at buckling failure in different wellbore geometries such as vertical, inclined, and curved wellbores. The buckling failure in these tests occurred in wellbores with a variety of orientations. The effects of torque, friction, flow rate, and tool joints on the sinusoidal and helical critical buckling stresses were discussed by Sun et al. (2015) in their paper. These effects might have a significant influence on the situation as it is. They came to the conclusion that a complete model is required to handle the many aspects of drillstring buckling, which may become a more troublesome issue with rising well depth and deviation. One of the primary arguments that supported their conclusion was this. One of the problems they encountered during their investigation was this. The drillstring will initially resemble a sinusoidal buckling while drilling inclined wellbores, and later in the drilling process, it will resemble a helical buckling. Due to the angle at which the drillstring is being inserted into the wellbore, this happens. The drillstring is frequently shown as a long beam because of how frequently its length-to-thickness ratio is rather high. The effectiveness of the drillstring is evaluated using this ratio. Divide the drillstring's whole length by its typical thickness to arrive at this ratio. You'll get a response from this.

A4. Wash out and twist-off

The drill pipes are susceptible to two typical types of failure: wash-out and twist-off. According to Moradi and Ranjbar (2009), the majority of these failures are thought to be the result of corrosion or mechanical fatigue-related damage. Corrosion is the process through which a drill pipe deteriorates as a result of the pipe's interaction with its environment. The interaction between the pipe and its surroundings causes this process to occur. The drill pipes are vulnerable to corrosion due to a variety of factors, including electrochemical oxidation, mechanical action, and the combined effects of mechanical activity and corrosive substances. These three distinct processes each have the potential to produce corrosion.

According to Knight et al. (2003), the washout is a non-critical kind of failure that is represented by a leak, crack, or microscopic hole in the drill pipe. Compared to other failure categories, this one is not as severe. This type of breakdown happens as a result of the drilling mud's tremendous pressure. The drill pipe's fracture surface would have a post-separation catastrophic failure as a result of the mud being forced under substantial pressure to flow from the pipe bore to the annulus, expand, and propagate into the pipe body. The type of event that has just taken place is referred to as a "twist-off" in Figure 4b.

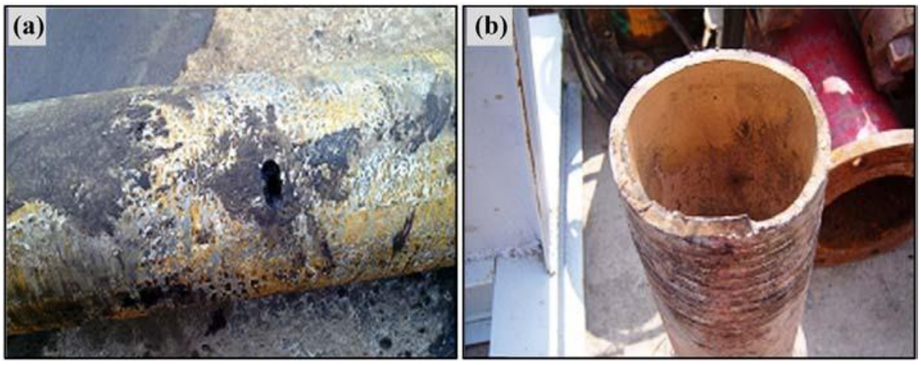

Figure. 4. Two examples given by Wang et al. (2011) are (a) the drillstring failing to washout and (b) the fracture surface twisting off.

The twist-off failure is one of the less frequent types of failures, but it has the potential to be quite severe and extremely expensive to fix. The washout failure is one of the most common types of failure. Based on information gathered from prior studies (Wang et al., 2011; Moradi & Ranjbar, 2009; Macdonald & Bjune, 2007), the failure analysis of the drillstring was conducted. These analyses revealed that about 95% of drill pipes failed due to a washout close to the bottom hole assembly, whereas the remaining 5% of drill pipes failed due to twisting off. While 22% of these failures occurred at the drill collars, the slips area was in charge of 65% of these failures. Die-marks produced by slip and tongs have the ability to concentrate stress and cause a complete fracture, claim Moradi and Ranjbar (2009). This is due to the formation of die-marks during an operative process. Dies are due to the fact that die-marks are made. As a result, as shown in Figure 5, there may be a chance that the surface of the pipe body may be permanently scarred. For a deeper understanding of the washout failures that occurred in the drill pipes, Figure 6 is made up of a series of pictures that have been reproduced and exhibited there.

Figure 5 (Moradi and Ranjbar, 2009) shows how die marks affect the failure of drill pipes.

DOI : https://doi.org/10.56452/2023-04/007

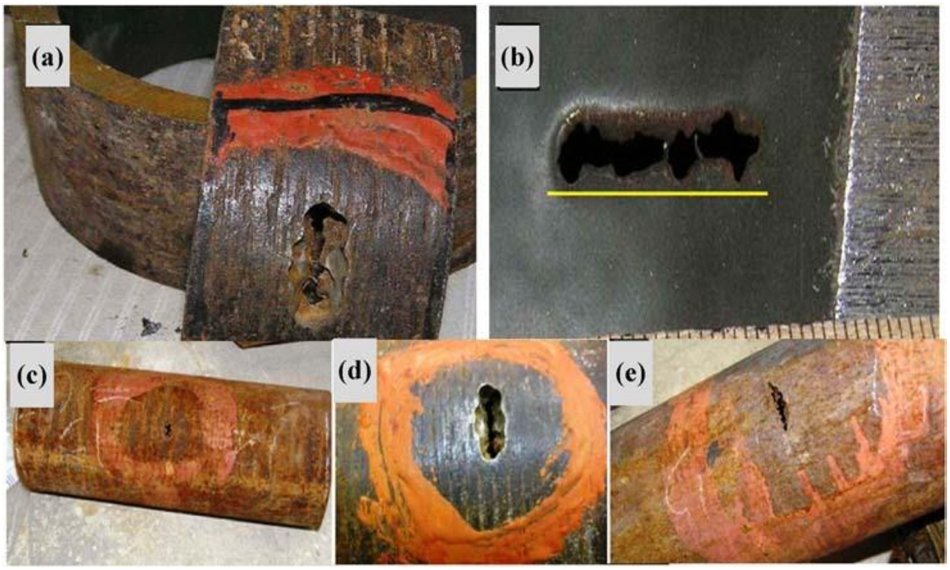

Figure 6: Moradi and Ranjbar (2009) claim that washout failures happened on the drill pipes' external surfaces.

A5. Other failure modes occurred in the drill pipes

Drill pipes are vulnerable to a broad range of failure modes during drilling an oil well, some of which include sticking, pipe-parting, collapse failure, and burst failure (Azar, 2015). One of the most frequent failure mechanisms is pipe sticking. Here are some other potential failure mechanisms in addition to those already mentioned. The forces that are delivered downhole can be unpredictable, even when wells are built with the utmost care, which frequently leads to failures like these. This could be explained by the fact that different depths are used to apply downhole forces. Figure 7 shows how the architecture of these damage mechanisms takes into consideration ductile fracture, brittle fracture, and fatigue.

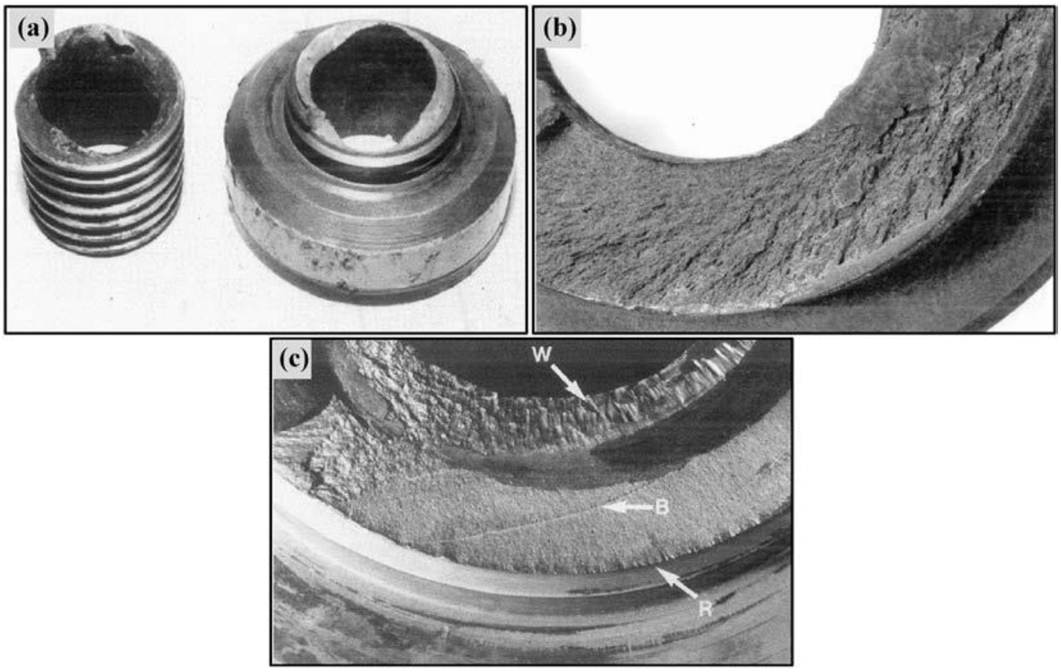

Figure 7 depicts the three most typical fracture types, ductile, brittle, and fatigue, in that order. The letters R, B, and W in Figure (c) stand for radial steps along the initiation area at the thread root, beach marks from fatigue, and wash-out, respectively, according to Macdonald and Bjune (2007).

Failure can occasionally happen at random points throughout the drill pipe's length as a result of external damage brought on by improper pipe handling techniques. This might happen anywhere along the drill pipe's length. In situations like this, stabilizers are frequently employed to lessen vibrations created by the drillstring and to increase the drilling operation's overall effectiveness. Stabilizers are also employed during borehole extension to improve the placement of the well, increase the stability of the wellbore, and enable faster production (Gulyaev et al., 2009). This is done in order to increase manufacturing speed. The drill pipe will be secured in a position that prevents it from being released and pulled out of the borehole if stabilizers are not present (Azar, 2015). The drill pipe cannot be drawn out of the borehole or released as a result. The pipe can, however, be removed from the well if it has any damage or if its weight exceeds the drilling rig's maximum permitted hook load. Mechanical pipe sticking, which happens when the drilled cuttings are not removed completely from the annulus, and differential-pressure pipe sticking, which happens when a section of the drillstring gets stuck in the mud cake (or fine solids), are the two most frequent types of pipe sticking failures. By correctly removing the drilled cuttings from the annulus, it is possible to prevent both of these types of pipe sticking failures. The mechanical pipe sticking is the more prevalent of the two types of pipe sticking failures.

The pipe will fail if the pipe separation fails and the associated tensile stress is greater than the ultimate tensile stress of the pipe material. This kind of failure occurs when the pipe gets trapped, necessitating a greater draw force to remove it. In other words, the pipe breaks as a result of this kind of failure. The weight of the pipe hanging in the hole above the stuck point will therefore be subject to an extra force as a direct result of this. This ultimately results in failure. According to Azar (2015), the drill pipe will undoubtedly break into several pieces due to the increasing strain.

B. Failure analysis of the drilling bits

A drilling bit is a piece of equipment used for cutting or boring that is attached to the end of the drillstring. In order to do this, the rock at the bottom of the pit is scraped, chipped, gouged, or ground. This makes it possible to drill through the rock. Drilling bits come in a huge variety of sizes and combinations. According to Xu et al. (2014), repeated impact forces that are required for breaking the rock in challenging downhole conditions may be the cause of considerable bit bouncing or drilling bit failure. This is a result of the bit material's weak mechanical properties combined with repeated impact pressures. The hammer bit is prone to a number of failure modes, including tooth loss, tooth fracture, tooth wear, and both micro- and macro-cracks, according to Kapitaniak et al. (2015). These many failures might result from a large variety of different situations. In the section that follows, you will find a brief explanation of each of these bit failures on its own.

B1. Tooth loss

The body of the drilling bit may deform plastically when it is crushed by teeth formed of a harder substance and is subjected to the effects of severe repetitive impact and rotation. When the body experiences the impacts of significant repetitive impact and rotation, this may occur. The shrink range—another term for the joint surfaces—between the tooth holes and the teeth has narrowed as a result, according to Moradi and Ranjbar's research from 2009. The tooth openings eventually grow brittle and finally wear out because of the frictional force that they exert over time. The bulk of the teeth that were damaged were those that were outside of the inclined plane that makes up the bit's end face (see Figure 8a).

B2. Tooth fracture

The tooth fracture is most likely the result of impact spalling since the fractured tooth includes a wide variety of spalling pits and grooves of various widths linked to one another by spalling bits. The fact that Figure (8b) depicts the broken tooth serves as evidence for this. Additionally, deeper and wider grooves that have developed as a result of the tooth erupting might cause crack extensions to form around spalling pits, which can lead to tooth fracture and localized spalling. The expansion of the tooth is what caused these grooves to appear. The tooth also develops fatigue fractures as a result of the many collisions, which increases the likelihood that the tooth may break (Harris & Jur, 2009).

Fig. 8. The three possible failure modes of the hammer bits are (a) tooth loss, (b) tooth fracture, and (c) tooth wear, according to Fan et al. (2011).

B3. Tooth wear

High-stress crushed abrasive wear, as shown in Figure (8c), happens when the compressive stress on the joint surfaces between the tooth and the abrasive particle is greater than the abrasive particle's breaking strength. High-stress crushed abrasive wear is another name for this type of tooth wear. As a result, when the tooth grinds against the abrasive particle, it wears it down and crushes it. As a direct result of this, a stress concentration will develop on the surfaces of the joints, and this stress concentration has the tendency to continuously crush the abrasive particles. As a direct result of the stress concentration, the wear-related damage to the tooth surfaces will rise. The increased abrasive wear on the tooth surfaces is due to the scouring effect, which occurs when compressed air mixed with many hard cuts is passed over something. When compressed air is passed over anything, this effect happens. Another frequent dental injury is a tooth scrape, which is easily caused when a tooth's flat surface comes into contact with a protrusion or an edge.

Drag bits, roller cone bits, and diamond bits are the three main categories that may be used to classify drilling bits, according to Wamsley Jr and Ford (2006). Although the drilling fluid is often used to remove the difficult drilling cuttings and circulate through passages in the bit, extending the bit's life, many other factors might influence how well the drilling bits work and how long they last. For instance, the operating temperature of the bit might have a big effect. One of the parameters that must be taken into account is the temperature of the drilling fluid. The number of times the drillstring rotates per minute, the force applied to the bit, the characteristics of the mud, the hydraulic efficiency, and the severity of the dogleg, if any, are a few examples of these variables. On the other hand, the main goal of this research is not to better understand these operational characteristics and how they affect the drilling bit.

Fig. 9. Sorted categories for drilling bits (Wamsley Jr. & Ford, 2006).

One of the processes in the drilling process involves chipping (when using drag bits) or crushing (when using roller cone bits), both of which produce vibration. There is nothing that can be done to eliminate this vibration, which is an inescapable component that affects the performance of the bits. In order to properly design drilling bits that can be used to drill extremely soft or ultra-hard formations and withstand high temperatures and prolonged run times, numerous experimental and numerical studies on a variety of drill bit materials were carried out. This was carried out in order to build drilling bits that would be effective in drilling formations that were either exceedingly soft or highly hard. In order to efficiently drill exceedingly soft or ultra-hard formations, the drilling bits have to be designed properly. This was done specifically to undertake the appropriate drilling bit design. For instance, when the WC-Co cemented carbide hammer bit was utilized for percussive drilling with the rock-breaking mechanism, Fan et al. (2011) assessed the factors that contributed to the failures of the tool. The bit was used by the authors in this investigation to carry out drilling that broke rock. They concluded that the mechanical properties of the material being utilized for the bit could not withstand the coupling action of impact fatigue, impact spalling, and abrasive wear. A unique Al2O3/WC-Co nanocomposite material was used as a replacement as a result; its micro-hardness, bending strength, and impact toughness were considerably improved.

Ehmann and Che (2014) looked at the efficiency of cutting polycrystalline diamond compact bits when turning rocks. We looked at the force reactions, the shear cutting, and the drilling rates in real-time. Utilizing polycrystalline diamond compact bits, only soft rocks like carbonates, shales, and unconsolidated sandstones are permitted for cutting. They cannot drill through quartzite, granite, chert, conglomerate, or chert, but they can drill through pyrite. The many motions that makeup force response include plowing, shearing, lateral contact, and frictional motions.

The results of several studies have improved the performance of hammer drilling bits. The strength and bit profile of the bit is being studied. The prevention of wear, force prediction, field monitoring, and dynamic process control were further considerations. The weight, torque, and depth of cut required to maximize the performance of a diamond hammer drilling bit were predicted by Karakus and Perez (2014). The level of production increased. They were able to swiftly spot drill bit wear by examining the temporal spectrum of the acoustic emission data. The breakdowns of tungsten carbide WC/Co rock drilling bits and blades were examined by Katiyar et al. in 2016. The initial mechanical, chemical, and high-temperature robustness of the WC/Co drill bit was excellent, but with time, it degraded to the point that it cracked.

B4. Bit balling

Drill cuttings may adhere to the bit when drilling in water-reactive clay or shale formations, which may result in bit balling. Using electrochemical and mechanical techniques for bit balling. The possibility for bit-balling sticking can be influenced by clay calcite, reactive clays with high cation exchange capacities, and borehole hydrostatic pressure (5000–7000 psi). Biting can be brought on by a number of things, including an excessive bit weight, an inadequate bit cutting structure projection due to bit choice or wear, an insufficient bit hydraulic system, or a low flow rate. Bit balling may be avoided most effectively by using anti-balling coatings. Rough bits, according to Javidi, Saeedikhani, and Omidi (2012), enhance the adhesive forces and surface area. A precisely designed metallic layer prevents bit balling and boosts the layer's strength.

In an effort to lessen bit balling during drilling operations, Luo et al. (2016) developed a newly created drill bit that could be used with a downhole air hammer that used reverse circulation. Three optimized drill bits were therefore created and produced. Each of these bits had two symmetrically positioned flushing nozzles that were 3 millimeters in diameter, two 8 millimeter diameter mid-pressure restoring grooves, and six 6 millimeter diameter suction nozzles that were evenly spaced throughout the layer.

An investigation was conducted by Ranjbar and Sababi (2012) to examine the failure analysis of a chrome-coated drilling bit under a range of drilling fluid characteristics based on circulation and influxes. The journal Scientific Reports reported the research team's results. Additionally, they looked at how operating factors like solid content and bottom-hole temperature affected the bits' lifespan. These variables include the solid content and bottom-hole temperature. The chrome-coated surface displayed scratches, spalling pits, micro and macro fractures, coated layer detachment, deep and shallow cuttings, and deep and shallow cuttings (Figure 10). The chrome-coated surface also experienced coated layer detachment, deep and shallow cuttings, and deep and shallow cuttings.

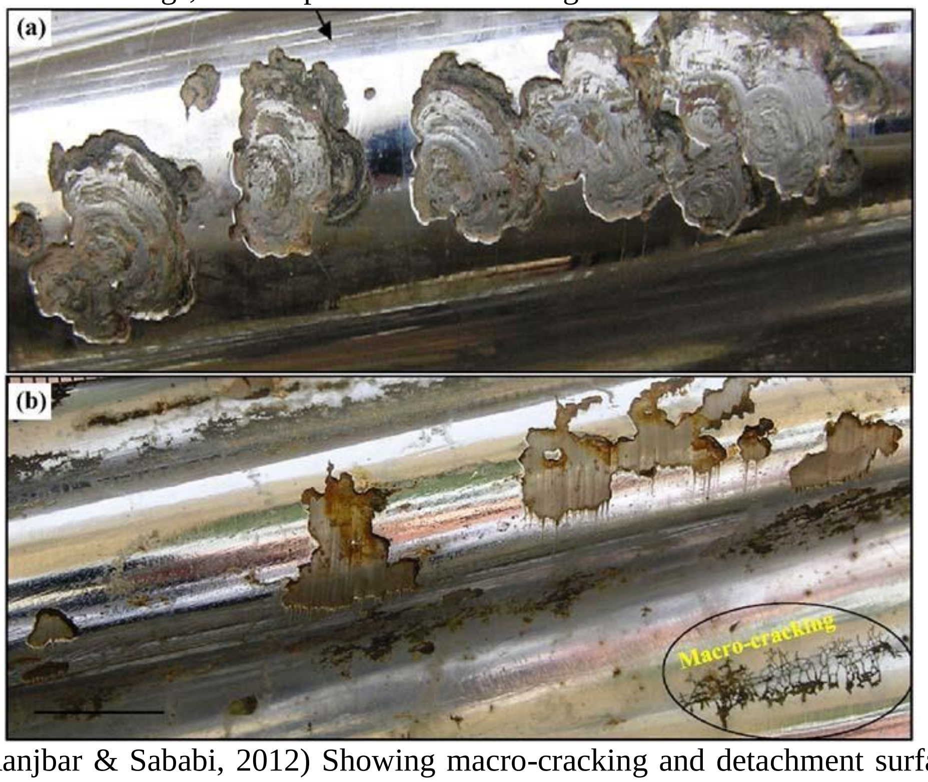

Fig. 10. (Ranjbar & Sababi, 2012) Showing macro-cracking and detachment surface failure of the chrome layer on the surface of chrome coated rotors (a).

C. Other failure modes occurred through the drilling process

The wellbore instability, which is regarded as one of the issues that can arise during the drilling operation, is influenced by the mechanical properties of the formation, the amplitude and distribution of the forces around the wellbore, as well as the properties of the drilling mud. Akhtarmanesh, Shahrabi, and Atashnezhad (2013) assert that wellbore instability can also affect sloughing or expanding shales as well as abnormally stressed shale formations.

In order to assess the importance of these mechanisms in the wellbore stability in relation to the physical and chemical properties of the shale as well as the thermodynamic conditions, the researchers Akhtarmanesh et al. (2013) investigated the primary mechanisms of the shale instabilities, which were the pore pressure transmission and the chemical osmosis. The transfer of pore pressure was shown to be the more important of the two methods. The results showed that chemical osmosis and pore pressure transfer were the two most important mechanisms. Shale formations were found to be capable of causing a number of issues, including partial or significant slumps, which can result in pipe sticking or poor hole conditioning, bit balling and bit floundering, as well as low-quality logging and drilling fluid contamination as a result of their mixing with dispersed active clay particles. Other problems that can be brought on by shale formations include contaminated drilling fluid and poor-quality logging. Shale deposits are the root cause of these issues.

Figure (11) from Zhang (2013) depicts the predicted borehole failures and wellbore sliding/shear failures along borehole trajectories with varied drilling orientations vs bedding planes. To increase the stability of the borehole, geological anisotropy and its effects on the horizontal stresses were taken into account. The gradient of slide failure in the weak planes was also determined. Tight hole occurrences and blocked pipe incidents are the two most common types of borehole instability. Both of these mishaps, which might endanger the environment and the employees, were caused by the hole collapsing (rock mechanical failure), improper hole cleaning, differential sticking, and deviation from the desired trajectory.

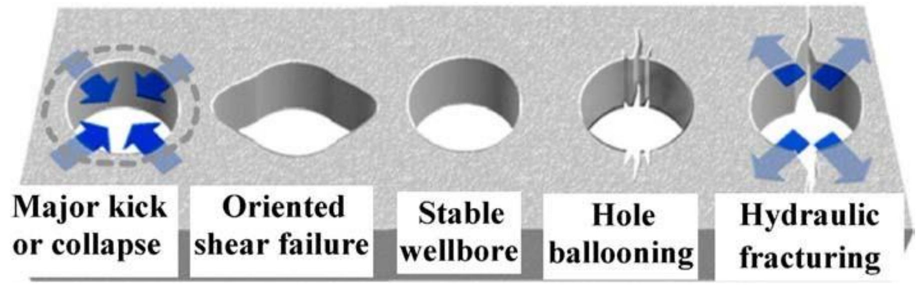

Figure 11 displays a schematic showing the connection between borehole failures and mud pressure (Zhang, 2013).

Conclusion

This review article examines drill pipe and drill bit failure analysis in order to comprehend downhole drilling conditions and pinpoint the contributing factors. This study aims to comprehend the downhole drilling conditions better. The most frequent types of breakdowns that can occur with drilling equipment were covered, along with a brief explanation of each. These types of failures include tooth wear and tooth fractures in addition to fatigue, vibration, buckling, washout, and twisting off. We briefly discussed a few other probable drilling process failure factors in the preceding section. These included mud contamination, hole variation, pipe sticking, and unstable boreholes.

To effectively reach the target zone and avoid extremely expensive drilling issues, it is crucial to have a thorough understanding of the drilling challenges and their causes. Additionally, answers to these drilling issues are crucial. Fatigue fractures, along with other types of metallurgical and mechanical failures, are to blame for the vast majority of failed drillstrings, according to the study reported in this article. The great majority of these cracks appeared as a result of various vibrations, slide cuts, and other anomalies along a similar line.

Additionally, a number of studies have offered some suggestions for lowering the possibility of a drillstring collapse. For instance, before inserting the drillstring into the borehole, one should make sure it is in good shape. Prior to starting the drill, this should be completed. Additionally, it is strongly suggested that a shock absorption device made of advanced alloys be mounted on a drillstring with high strength to make up for the detrimental impact that the absence of drilling mud has on air drilling operations. This is done to make up for the fact that the air drilling technique does not use drilling mud. Additionally, it is important to take into account developing a novel drillstring that enables a more efficient drilling process or altering the drillstring surface utilizing a more advanced coating technology.

References

Agostini, C. E., & Nicoletti, R. (2014). Dynamic modeling and vibration analysis of oilwell drillstring during backreaming operation. In Topics in Modal Analysis I, Volume 7: Proceedings of the 32nd IMAC, A Conference and Exposition on Structural Dynamics, 2014 (pp. 123-131). Springer International Publishing.

Akhtarmanesh, S., Shahrabi, M. A., & Atashnezhad, A. (2013). Improvement of wellbore stability in shale using nanoparticles. Journal of Petroleum Science and Engineering, 112, 290-295.

Azar, J. (2015). Drilling Problems and Solutions, Petroleum Engineering Handbook, SPE International Publication, pp. 433–454.

Fan, Y., Huang, Z., Gao, D., & Li, Q. (2011). Experimental study of an Al2O3/WC–Co nanocomposite based on a failure analysis of hammer bit. Engineering Failure Analysis, 18(5), 1351-1358.

Fang, H., & Duan, M. (2014). Offshore operation facilities: equipment and Procedures. Gulf professional publishing, Elsevier Science Limited, pp. 141–340.

Fangpo, L., & Xin, X. (2011). Simulation technology in failure analysis of drill pipe. Procedia Engineering, 12, 236-241.

Ghasemloonia, A., Rideout, D. G., & Butt, S. D. (2015). A review of drillstring vibration modeling and suppression methods. Journal of Petroleum Science and Engineering, 131, 150-164.

Gulyaev, V. I., Solov'ev, I. L., & Gorbunovich, I. V. (2009). Stability of drillstrings in ultradeep wells: an integrated design model. International Applied Mechanics, 7(45), 772-779.

Hajianmaleki, M., & Daily, J. S. (2014). Advances in critical buckling load assessment for tubulars inside wellbores. Journal of Petroleum Science and Engineering, 116, 136-144.

Hakimi, H., & Moradi, S. (2010). Drillstring vibration analysis using differential quadrature method. Journal of Petroleum Science and Engineering, 70(3-4), 235-242.

Harris, D., & Jur, T. (2009). Classical fatigue design techniques as a failure analysis tool. Journal of failure analysis and prevention, 9(1), 81-87.

Javidi, M., Saeedikhani, M., & Omidi, R. (2012). Failure analysis of a gas well tubing due to corrosion: a case study. Journal of failure analysis and prevention, 12, 550-557.

Kapitaniak, M., Hamaneh, V. V., Chávez, J. P., Nandakumar, K., & Wiercigroch, M. (2015). Unveiling complexity of drill–string vibrations: Experiments and modelling. International Journal of Mechanical Sciences, 101, 324-337.

Karakus, M., & Perez, S. (2014). Acoustic emission analysis for rock–bit interactions in impregnated diamond core drilling. International Journal of Rock Mechanics and Mining Sciences, 68, 36-43.

Katiyar, P. K., Singh, P. K., Singh, R., & Lava Kumar, A. (2016). Modes of failure of cemented tungsten carbide tool bits (WC/Co): A study of wear parts. International Journal of Refractory Metals and Hard Materials, 54, 27-38.

Knight, M. J., & Brennan, F. P. (1999). Fatigue life improvement of drill collars through control of bore eccentricity. Engineering Failure Analysis, 6(5), 301-319.

Knight, M. J., Brennan, F. P., & Dover, W. D. (2003). Controlled failure design of drillstring threaded connections. Fatigue & Fracture of Engineering Materials & Structures, 26(11), 1081-1090.

Kreuzer, E., & Steidl, M. (2012). Controlling torsional vibrations of drill strings via decomposition of traveling waves. Archive of Applied Mechanics, 82, 515-531.

Liao, H., Guan, Z., Shi, Y., & Liu, Y. (2015). Field tests and applicability of downhole pressurized jet assisted drilling techniques. International Journal of Rock Mechanics and Mining Sciences, 75, 140-146.

Lin, Y., Qi, X., Zhu, D., Zeng, D., Zhu, H., Deng, K., & Shi, T. (2013). Failure analysis and appropriate design of drill pipe upset transition area. Engineering Failure Analysis, 31, 255-267.

Lukawski, M. Z., Anderson, B. J., Augustine, C., Capuano Jr, L. E., Beckers, K. F., Livesay, B., & Tester, J. W. (2014). Cost analysis of oil, gas, and geothermal well drilling. Journal of Petroleum Science and Engineering, 118, 1-14.

Luo, Y., Peng, J., Li, L., He, J., Gan, X., Yin, K., & Zhao, Z. (2016). Development of a specially designed drill bit for down-the-hole air hammer to reduce dust production in the drilling process. Journal of Cleaner Production, 112, 1040-1048.

Macdonald, K. A., & Bjune, J. V. (2007). Failure analysis of drillstrings. *Engineering Failure Analysis*, *14*(8), 1641-1666.

Moradi, S., & Ranjbar, K. (2009). Experimental and computational failure analysis of drillstrings. Engineering Failure Analysis, 16(3), 923-933.

Patil, P. A., & Teodoriu, C. (2013). A comparative review of modelling and controlling torsional vibrations and experimentation using laboratory setups. Journal of Petroleum Science and Engineering, 112, 227-238.

Ranjbar, K., & Sababi, M. (2012). Failure assessment of the hard chrome coated rotors in the downhole drilling motors. Engineering Failure Analysis, 20, 147-155.

Sahebkar, S. M., Ghazavi, M. R., Khadem, S. E., & Ghayesh, M. (2011). Nonlinear vibration analysis of an axially moving drillstring system with time dependent axial load and axial velocity in inclined well. Mechanism and Machine Theory, 46(5), 743-760.

Sun, Y., Yu, Y., & Liu, B. (2015). Closed form solutions for predicting static and dynamic buckling behaviors of a drillstring in a horizontal well. European Journal of Mechanics-A/Solids, 49, 362-372.

Tang, L., & Zhu, X. (2015). Effects of the difference between the static and the kinetic friction coefficients on a drill string vibration linear approach. Arabian Journal for Science and Engineering, 40, 3723-3729.

Wamsley Jr, W. H., & Ford, R. (2006). Introduction to Roller-Cone and Polycrystalline Diamond Drill Bits. Petroleum Engineering Handbook, 2, 221-264.

Wang, R. H., Zang, Y. B., Zhang, R., Bu, Y. H., & Li, H. Z. (2011). Drillstring failure analysis and its prevention in northeast Sichuan, China. Engineering Failure Analysis, 18(4), 1233-1241.

Xu, S., Liu, Y. Z., Zhou, L. Y., Yan, Y. M., & Zhu, H. W. (2014). Failure analysis of the 18crni3mo steel for drilling bit. Journal of Failure Analysis and Prevention, 14, 183-190.

Xue, Q., Leung, H., Wang, R., Liu, B., Huang, L., & Guo, S. (2016). The chaotic dynamics of drilling. Nonlinear Dynamics, 83, 2003-2018.

Zhang, J. (2013). Borehole stability analysis accounting for anisotropies in drilling to weak bedding planes. International journal of rock mechanics and mining sciences, 60, 160-170.

Zhu, X. H. (2016). Failure analysis and solution studies on drill pipe thread gluing at the exit side of horizontal directional drilling. In Handbook of Materials Failure Analysis with Case Studies from the Oil and Gas Industry (pp. 153-173). Butterworth-Heinemann.