Drill Pipe Failures Investigation: Causes and Solutions in Oil Industry (Review)

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Abstract

This effort focuses on the failure of drilling pipes due to various drilling problems. These problems include buckling, fatigue, collapse, and explosion. The issue of torsion was identified, along with the indicators of torsion occurrence and its causes. The research also discusses the risks resulting from torsion and how to treat it, as well as reduce its occurrence. Additionally, the study delves into the effect of torque on the twisting of drill pipes and calculates the angle of torsion using a mathematical relationship. The research also explores the impact of formations on distortion and identifies those with a high percentage of distortion. Furthermore, it delves into the effect of Revolution per Minutes (RPM) and Weight on Bit (WOB) on drill pipe, buckling and the relationship between them. On other hands, the study covers dents, their types, and the calculation of the strength of wall loss caused by dents using a mathematical equation. options to prevent or reduce buckling are discussed. Finally, it was concluded that the torque must be properly managed by adjusting the drilling parameters, such as the weight on the drill bit and the rotation speed, so that the pipe does not become twisted, and also so that the shear stress generated by drilling is not applied. The torque does not exceed the ultimate shear stress of the pipe. It is crucial to monitor the drill shaft for small cracks to prevent potential explosions and serious issues over time.

Keywords: *pipe, failures, fatigue, collapse, torque.*

1. Introduction

In oil and gas exploration, drill pipes are crucial components that often go unnoticed. They are subjected to harsh conditions such as immense pressure, corrosion, and vibrations, which can lead to catastrophic collapses. Some studies highlight the importance of analyzing these failures to ensure smoother and safer drilling operations [1]. Collapses occur when external pressure exceeds the strength of the pipe. However, this seemingly simple scenario involves a complex interaction of material composition, pressure dynamics, corrosion environments, and fatigue [2]. To prevent and mitigate drill pipe collapse, a multi-faceted approach is required, involving the use of high-strength materials, meticulous pressure management, corrosion-resistant coatings, and fatigue-resistant practices [3]. By understanding the diverse causes of drill pipe burst and implementing these solutions, the industry can ensure the smooth flow of energy while safeguarding personnel and the environment [4]. Drill pipes that twist are crucial for exploring and extracting natural resources, especially in the oil and gas industry. These specialized tubular components are essential parts of the drill string, which is a critical assembly of interconnected pipes that aid the drilling process [5]. The term "twisting" in the context of drill pipes refers to the torsional or rotational forces these pipes experience during drilling operations [6]. Twisting drill pipes primarily transmit torque and drilling fluid from the surface to the wellbore's deep drill bit [7]. The speed of rotation, known as RPM, during drilling operations can impact the likelihood of drill pipe twist-offs [8]. WOB contributes to the overall torsional stress on the drill string, including the drill pipe [9]. If more weight on the bit are applied, the torque increases, leading to higher torsional forces on the pipe. If these forces exceed the pipe's capacity to withstand twisting, it can result in twist-off failure [10]. The design and material properties of the drill pipe play a critical role [11]. In response to the rapidly increasing global energy consumption, there has been a growing focus on ultra-high temperature and ultra-high-pressure petroleum and gas wells within the industry [12]. However, due to the complex downhole environment of such wells, the stress on the drill pipe during the drilling process is very challenging [13]. As a result, drill pipe failures often occur in ultra-deep well drilling. In recent years, numerous drill-pipe failures have been reported in ultra-deep wells, and some areas have experienced serious drill pipe failures [14]. Many scholars have attempted to explain the reasons behind these failures [15]. The primary objective of this study is to pinpoint the key reasons for the failure of drilling pipes and to develop effective solutions for them. What is innovative about this is identifying the factors that impact the success of these solutions.

2. Related studies:

Numerous studies have investigated pipe failure, as indicated in Table 1.

Table. 1 The previous studies related to pipe failure.

Researcher	Year	Finding and result
Yu et al	2022	Investigated the failure of steel drill pipe S135. Discovered that a crack originated from a corrosion pit due to stress concentration. The crack extended along the circumference during a lifting operation, ultimately leading to sudden fracturing [16].
Liu et al	2021	Analyzed the failure of an aluminum alloy drill pipe. Studied the formation of pits and horizontal cracks. Attributed the failure to the brittleness sensitivity of the second phase and inclusions in corrosive media [17].
Ahmed et al	2020	Investigated a twisted-off failure specimen of heavy-weight drill pipe (HWDP). Determined that the HWDP failed due to corrosion fatigue mechanism [18].
Luo et al.	2020	Provided a modified model for S-N data. Revealed correlation between fatigue life, fatigue limit, and equivalent stress amplitude. Examined fatigue fracture mechanism using scanning electron microscopy [19].
Zhang et al.	2019	performed an analysis of the chemical composition, mechanical properties, and microstructures of failed drill pipe materials through experiments. They then used the finite element method to study the static stress characteristics and fatigue life of drill pipe joints under multi-axial alternating loads. The study found that the main factor of failure was the alternating load [20].
Abdo et al	2017	Developed an experimental setup to mimic downhole vibration modes. Investigated drill-pipe fatigue failure due to cyclic stresses. Addressed research deficiency in quantitative assessment methods of drill-pipe fatigue [21].
Huang et al.	2017	Built an experimental model for drill pipe erosion based on the micro-cutting model. Discovered that gas injection volume has a greater impact on erosion compared to the rate of penetration. A high rate of penetration reduces the erosion wear of the drill pipe [22].
Liu et al.	2016	Analyzed axial cracking failure while considering service conditions, material quality, and stress corrosion mechanism. Conducted measurements and inspections on crack surfaces and corrosion products. Established the relationship between drill pipe erosion wear loss and drilling parameters [23].
Zamani et al.	2016	reviewed past research on drill pipe failures and discussed various metallurgical and mechanical factors that could lead to failure. They argued that complex loading, combined stresses, and different types of vibrations may be the primary factors, and they also suggested that fatigue crack is the root cause of drill-pipe failure [24].

3. Causes of Drill Pipe Failures:

The causes of drill pipe failures can be classified into three categories:

3.1. Mechanical causes:

Failures can occur due to excessive axial or torsional forces acting on the drill pipe. Poor design, improper handling, and excessive torque can weaken the pipe, making it vulnerable to collapse or bursting [25].

3.2. Fatigue causes:

Repetitive cyclic loading and unloading can lead to fatigue in the drill pipe. Environmental factors such as vibration, temperature variations, and high-pressure cycles can contribute to fatigue failures [26].

3.3. Corrosion causes:

Corrosion weakens the structural integrity of the drill pipe. Exposure to corrosive fluids, improper storage, and lack of corrosion protection measures can result in premature failures.

3.4. Causes of twisting in drill pipes:

1. Excessive force applied by the rotary table

2. Drill pipe fatigue failure due to stuck pipe problems in the lower sections

3. High torque deflection: Twist-off is more likely to occur when the torque-induced shearing stress exceeds the pipe's ultimate shear stress. This often happens in directional and horizontal wells where the torque is more than 80 kIb ft.

4. Rough pipe handling: Improper handling of drill pipes can lead to twist-off incidents [27]

4. Mathematical Calculations and Data Management:

4.4.1. Calculation The buckling force Fp: bucking force can be calculated by using equation 1 [28]

$$fp = \sqrt{\frac{4E\ \mathrm{w}\ \sin\alpha}{r}} \quad \dots \dots\dots\dots\dots\dots\dots\dots (1)$$

Fp = buckling force lb

W=distributed buoged weight of casing (lbm/in)

α=well bore angle

E=pipe bending stiffness (psi)

r=radial annular clearance (in)

Ex; $E=30\times10^{6}$ psi

W=0.463 lbm/in

r=1.61 in

4.2. Effect torque on twist-off drill pipe

The formula for torque (T) is given by using equation 2 [29]:

Using Equation 2 and the data from the first three columns of Table 2 to calculate the torque values.

$T=\frac{\pi}{30}\times$ Torque factor × Diameter × shear strength (2)

Where:

- π is the mathematical constant pi (approximately 3.14159).
- Torque Factor is a dimensionless factor that considers various factors, including the type of connection, lubrication, and other conditions. (lb-ft)
- Diameter is the outer diameter of the drill pipe(inch)
- Shear Strength is the shear strength of the material of the drill pipe(psi)

4.3. Calculate the twist angle:

When a rod is subjected to torque it undergoes twist [30], which is given by using equation 3

$\Theta=\frac{T\,l}{G\,J}$ radians ……………..(3)

Where

Θ = angle of twist (radians) (can be >2π)

L = length of section(ft)

T = torque (lb-ft)

G = modulus of rigidity(psi).

$G=\frac{E}{2(1+v)'}$ (4)

J=Polar moment of inertia(in^4)=$\frac{\pi}{32}(OD^4-lD^4)$ …………(5) [31]

and E = modulus of elasticity, psi, and v = Poisson's ratio

4.4. Calculation of crack growth

Two equations can be used to predict crack growth: The Paris equation (Eq. 6) or the Forman equation (Eq. 7). The Forman equation is considered superior for design purposes as it takes into account the ratio of minimum stress to maximum stress (R). [32].

$\frac{da}{dN}=C\Delta K^n$ **(Paris equation 6)**

$\frac{da}{dN}=\frac{c\Delta K^n}{(1-R)KIc-\Delta K}$ **(Forman equation 7)**

5.Results:

This relationship shows that the lateral buckling force Fp decreases as the square root of the lateral distance r increases. In practical terms, this means that as the drill string gets closer to the wellbore wall, the force needed to prevent buckling increases significantly. Conversely, when the drill string is farther from the wellbore wall, the necessary lateral buckling force decreases as shown in fig. 1.

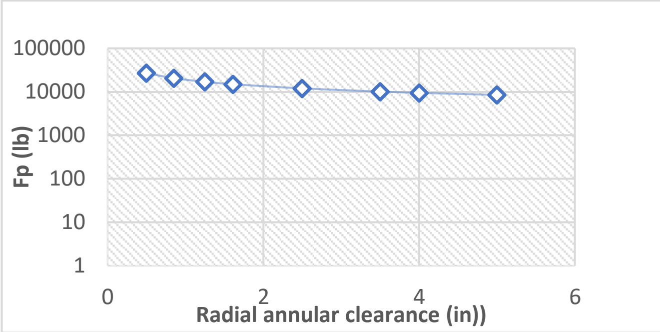

Fig. 1 Relationship between Fp and radial annular clearance

If the shear strength of the material changes, the required torque for twist-off in the drill pipe will also change proportionally and as shown in fig.2.

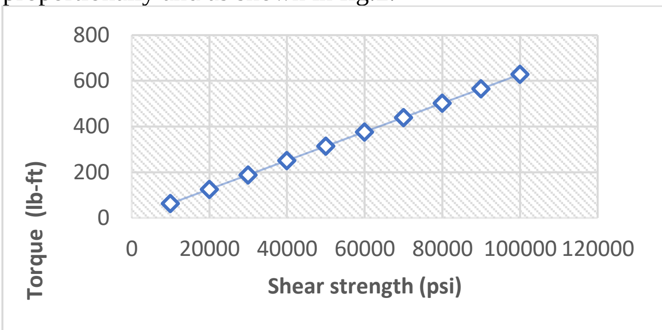

Fig. 2 The relationship between shear strength and torque

The Weight on Bit (WOB) calculation for twist-off in pipe failure involves considering the tensile yield strength of the drill pipe and as illustrated in fig. 3.

When twist-off occurs, the maximum WOB can be calculated using equation 14 [33]:

$WOB=\frac{\pi\times drill\ pipe\ OD\times Yield\ strength}{4}$ … … .. (14)

Where:

- π is the mathematical constant pi (approximately 3.14159).
- Drill Pipe OD is the outer diameter of the drill pipe. (in)
- Yield Strength is the tensile yield strength of the drill pipe material.

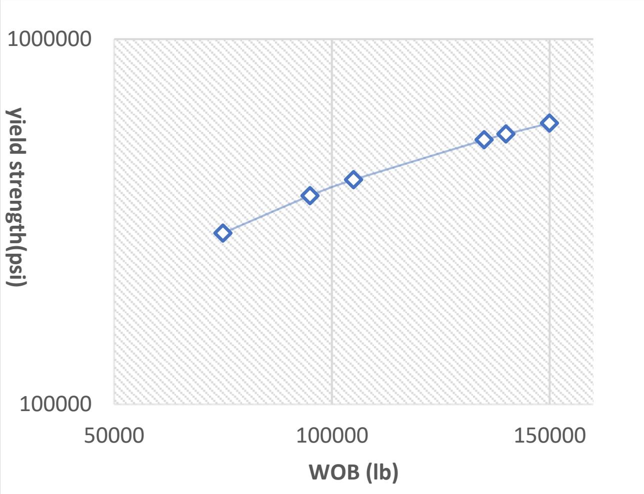

Fig.3 Relationship between WOB and tensile yield strength

When using the Forman Crack Growth Model to calculate crack growth rate, an initial crack size is assumed and used to calculate the stress intensity factor range for the first cycle. The crack growth increment for that cycle is then calculated, and is added to the previous crack size to obtain the new crack size and as shown in fig.4. This process is repeated until the crack has grown sufficiently to reach the critical stress intensity factor.

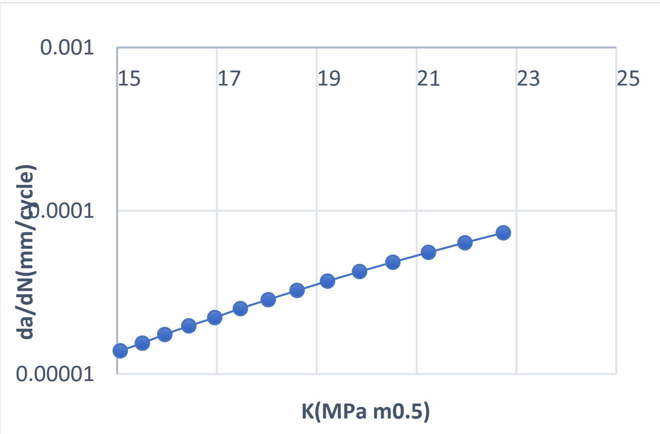

Fig.4 Crack growth rate vs stress intensity range for specimen

The relationship between total lifespan and temperature is usually inversely proportional. Higher temperatures can speed up degradation processes, such as chemical reactions and mechanical wear, which can shorten the total lifespan of a component. Conversely, lower temperatures can slow down these processes, potentially extending the total lifespan. However, extreme temperatures can introduce new failure modes or worsen existing ones, complicating the relationship. Therefore, it's important to take into account the specific material, environmental conditions, and operating parameters when evaluating the impact of temperature on total lifespan as shown in fig. 5

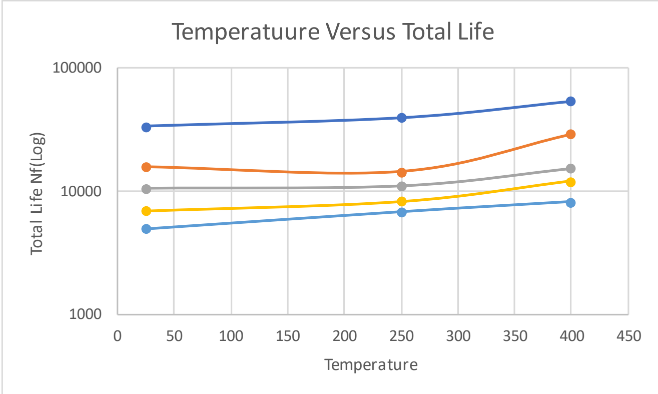

Fig. 5 Temperature versus total Fatigue life

6. Discussion

The problem of twisting drilling pipes is a crucial issue in the field of petroleum engineering. It can result in operational delays, escalated costs, and in the most severe instances, it can lead to accidents and significant human and material losses. Therefore, it is essential to thoroughly analyze and discuss this topic to comprehend its causes, signs, prevention, treatment, and various effects, as has been previously undertaken. In drilling operations, it's important to monitor torsional torque indicators as they can signal early symptoms of twisting. The greater the deviation of the torque during drilling, the higher the likelihood of twisting. Twisting of drill pipes can be caused by factors such as high torque, excessive load from the drill bit or fluid pressure, and passing through complex geological terrains with high pressures. This risk is particularly notable in directional and horizontal wells where the torque exceeds 80 kilo-pound feet. Higher torque levels increase stress on the pipes, raising the possibility of twisting. The angle of twisting varies based on geological and drilling conditions. The pressure on pipes and the risk of twisting increases with large twisting angles and high torque. Increasing the pipe diameter also leads to a greater twisting angle. Large diameter pipes with a greater cross-sectional area can withstand higher torques and are less likely to twist due to greater resistance to torsional forces. As the drill string gets closer to the wellbore wall, the lateral bending force needed to resist buckling significantly increases. Additionally, geological formations play a role in twisting probability - complex formations and hard rocks increase the likelihood of pipe twisting, while soft formations have a lower probability as in table 2. In harder formations, more torque is required, increasing the chances of twisting and necessitating a halt to the drilling process. Once a distortion is discovered, it is important to prevent any additional damage. The depth at which the distortion occurred needs to be determined in order to address the problem. This can be achieved by monitoring the drilling operations and using appropriate equipment. Fatigue pipe failure happens due to repeated cyclic loading and unloading, which leads to the initiation and propagation of cracks in the pipe material. Factors such as material defects, weld quality, operational

Table **2 The effect of formation on twist-off drill pipes**

Formation Type	Effect on Twist-off Drill Pipe Failure
Soft Formation	Reduced likelihood of twist-off due to lower drilling torque and drag.
Hard Formation	Elevated risk of twist-off due to higher drilling torque and drag.
Abrasive Formation	Higher chances of abrasive wear on drill pipe connections, potentially leading to premature failure.
Unstable Formation	Elevated risk of twist-off due to unpredictable drilling conditions such as borehole collapse or instabilit
Fractured Formation	Increased risk of twist-off due to irregular borehole conditions and potential torque fluctuations cause encountering fractures.

conditions (e.g., pressure, temperature, vibration), and external factors (e.g., corrosion, abrasion) can all contribute to fatigue failure. Detection and prevention strategies include regular inspection using techniques like non-destructive testing, implementing fatigue-resistant materials, optimizing operational parameters, and employing predictive maintenance techniques to monitor fatigue damage accumulation over time. Finally, the importance of designing and estimating the strength of pipes in wells with high pressure and high temperature was discussed. The study provides a detailed analysis of several models for estimating blast strength. It recommends the Clever-Stewart model as the best design option and emphasizes the importance of considering axial loads in collapse calculations. The study also suggests using the API model to estimate collapse. It emphasizes the importance of precise engineering and effective analysis for safety and success in difficult petroleum operations. The project proposes target probabilities and corresponding safety factors for different failure scenarios, highlighting the importance of considering consequence levels in design. For example, burst failure is categorized as high consequence due to its potential for severe environmental and safety ramifications, while collapse failure is seen as low consequence. Finally, the project discusses drilling methods and presents conclusions drawn from parametric collapse Finite Element Analysis (FEA) simulations. It highlights factors such as ID wear, wall eccentricity angle, dogleg bending, and axial compression in influencing casing collapse resistance. Geological formations can change rapidly, necessitating real-time adjustments in drilling parameters. Sudden changes in the geological characteristics may lead to unexpected stress on the drill string, raising the risk of torsional issues. Continuous monitoring and adaptation of drilling practices are vital to address variations in formation properties. In conclusion, the characteristics of geological formations play a crucial role in influencing the risk of twist-offs in drill pipes. As illustrated in table 4, "Drillers need to have a solid understanding of the subsurface conditions and adjust drilling practices accordingly to maintain the integrity of the drill string. This is essential for ensuring safe and efficient drilling operations. Continuous monitoring, real-time adjustments, and adherence to best practices are crucial in mitigating the impact of formation characteristics on drill pipe integrity. Figures 6, 7, 8,9 and 10 show the other results and effects factors. Table 3 illustrates the neurons input

Fig. 6 The effect of formation on twisting off drill pipe

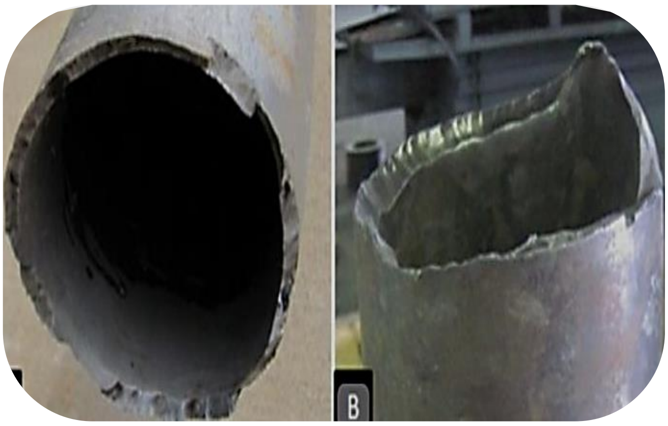

Fig. 7 Fatigue Failure at laboratory.

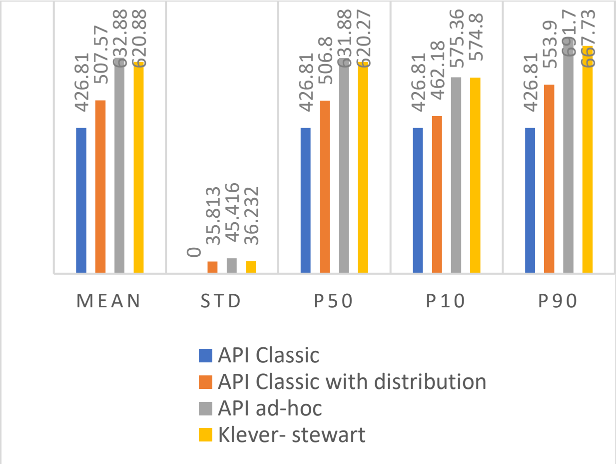

Fig. 9 Mean, standard deviation, median, P10 and P90 values for each model given in the bar

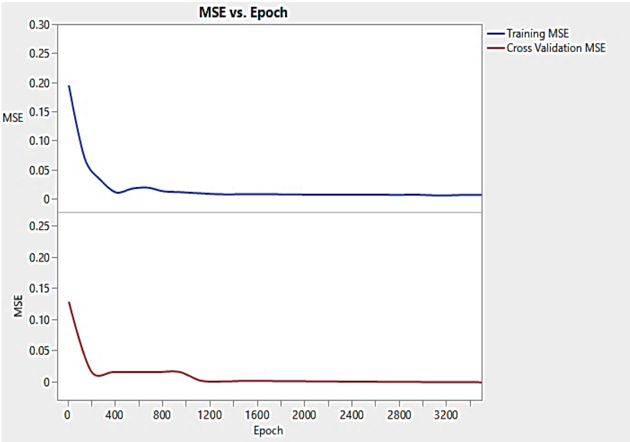

Fig. 8 Pressures effect on pipes

Table 3: The neural JMB input.

No.		Input data neurons								Biased
		MD	**Force**	**WOB**	**TQ**	**INC**	**PV**	**YP**	**Lithology**	
Hidden layers neurons	**a**	-11.906	9.8001	-0.3702	-0.078	-0.875	- 3.768	13.88	-0.321	-377.6074
	b	38.1006	9.356	-0.977	-1.577	-1.925	4.274	-2.351	1.518	272.294
	c	-24.7010	-0.0559	-0.530	1.185	1.707	-4.415	-1.590	0.925	-324.4073
	d	-27.900	-5.1080	1.414	0.8302	0.840	-1.731	-0.879	-2.914	-2507.012
	e	-7.9017	3.9013	0.257	-0.7020	-3.614	2.355	-1.910	-2.612	-1809.725
	f	-42.319	-0.7912	0.048	-0.4009	-4.671	-4.976	-2.801	1.634	-579.8015
	g	35.840	-1.944	2.595	3.0608	3.182	7.623	-11.81	0.655	576.189
	h	0.493	0.3707	-1.223	0.1902	1.4089	-0.452	-2.741	-0.0645	-3.5047
		Hidden layers neurons								**Biased**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
Output layers		17.264	17.891	11.33	-6.492	1.9805	-13.807	-13.808	3.154	18.207

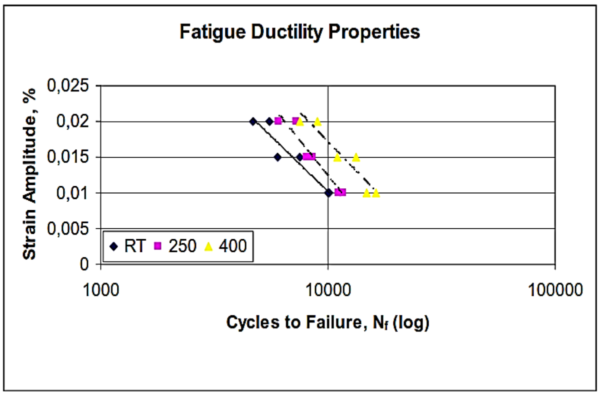

Fig.10 Fatigue Ductility Parameters

Conclusions:

It's essential to use high-quality materials such as stainless steel or corrosion-resistant aluminum to ensure that the pipes can withstand harsh operating conditions. Elevated temperature can speed up material deterioration and reduce the expected service life of pipes. Fatigue tube failure treatment involves replacing the damaged tube, which is a costly process that includes removing the damaged tube and installing a new one with the appropriate specifications. Emphasizing the significance of accurately designing piping in HPHT wells, where a design error can result in serious accidents. The study indicates that there are various methods for calculating the force of explosion and collapse, and employing the appropriate method necessitates a precise comprehension of the data and real-life circumstances. Based on simulation and analysis, a preferred model for piping design can be determined, like the Klever-Stewart model for estimating burst force, emphasizing the importance of choosing the most appropriate model for safety and efficiency. As the deflection angle increases, the drill pipe experiences more twisting because a hole with a high deflection angle requires a greater rotational force. As a result, the rotational force causes the drill pipe to twist. Increasing the diameter of the pipe reduces the amount of twisting. Furthermore, increasing the number of revolutions per minute increases the torque. When the weight of the drill bit is increased, it also increases the torque because it adds to the load. On the other hand, if the weight of the drill string is lost, it indicates twisting of the drill pipe, which can weaken its structural integrity. Torsion occurs in solid geological formations due to the high penetration rate and, consequently, high torque required. The risk of twisting drill pipes can lead to drill string failure, reduced drilling efficiency, and safety hazards. It also impacts directional drilling by altering the well's drilling path. To minimize drill pipe twisting, it's essential to utilize tools that resist twisting, like centralizers and torque management, and to control drilling parameters and the drill bit. Additionally, enhancing the properties of the drilling fluid can help prevent this issue.

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