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# Experimental Study on Frictional Wear of Casing

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**Abstract:** With development of drilling technology, deep well, ultra deep well, high angle well, directional well, extended reach well and horizontal well are taking more and more proportion. Meanwhile, the problem of serious frictional wear between drill pipe and casing are becoming more significant due to long time of drilling, high probability of dogleg severity, high contact normal stress between drill pipe and casing etc. At present, known factors influencing wear of casing mainly include contact force between drill pipe and casing, frictional factor, wearing time of drill pipe and casing, contact position between drill pipe and casing, lubrication performance of drilling fluid, dogleg severity and materials of dill pipe and casing. Through study in this paper, wear of downhole casing will be studied to reduce drilling accident and retrieve economical loss, and provide technical guidance for drilling of more complicated well as well.

**Keywords** Drill Pipe; Casing; Friction; Wear; Experiment

## INTRODUCTION

During process of drilling, due to complexity of movement of drill pipe, contact position between drill pipe and casing is not fixed, which further results in irregularity of wear shape on the casing. Wear of internal wall of casing is variously shaped, including uniform shape, crescent shape and bilge shape, among which the crescent shaped wear is most typical. Crescent shaped wear is the main study object of this paper. In that case, wear of the casing is shaped as crescent, with a radius same to that of drill pipe[Hou *et al.*, 2001]. Three parameters are mainly used for describing shape of wear on casing: radius of crescent shape, wearing amount and length of wear. Decrement of strength of worn casing is mainly due to reduction of wall thickness of casing. Frictional wear between drill pipe and casing is a complicated engineering problem[Lin *et al.*, 2004]. It is found by domestic and foreign researchers through a lot of researches that wear of casing is mainly caused by rotation of drill pipe; therefore, in the experiment part of this paper, rotation frictional wear between drill pipe and casing will be mainly discussed.

Drill pipe/casing frictional wear experiment machine has been developed to simulate different downhole conditions, including temperature, normal force, rotation speed of drill pipe, wearing time of casing, performance of drilling fluid, steel grade of drill pipe and casing and performance of completion cement etc[Wu et al., 2004]. Selected combination of conditions is adopted for drill pipe/casing frictional wear experiment or comparison experiment. Self-developed dual-channel digital amplifier realizes LCD and computer display of normal force, friction force, rotation speed, rotation time, temperature and working time on the experiment machine, and it is capable of setting experiment force, rotation speed of main shaft, wearing time and working temperature according to actual requirements. With simulated down hole working conditions, experiment machine studies rotation frictional wear between external wall of drill pipe and internal wall of casing under preset conditions. In the experiment, casing is fixed to fixture of outside specimen (casing) by cement to simulate completion of drilling well, and lever force system is adopted for applying normal stress on casing and drill pipe. The experiment machine is capable of studying influence of drill fluid on wear of drill pipe and casing under different temperature and conducting comparison experiments under the same temperature. Temperature plays a critical role in friction. It can change performance of drilling fluid, or even material characteristics of friction pair surfaces. There is certain breakthrough temperature for absorption film, exceeding which the absorption film will be peeled off and unidirectional and lubricant will lose efficacy, and frictional factor of friction pair will be further increased. Heater will be installed in the corrosion box and data will be transmitted to control panel through temperature sensor. Temperature required for the experiment can be positively preset on the control panel as well. Once the drilling fluid reaches required temperature, heating will be stopped automatically to keep constant temperature.

## EXPERIMENT CONDUCTED

### Experiment preparation

Specimen processing and notices: 51/2 inch casing material is used as casing specimen, of which the diameter is 139.7mm and wall thickness is 8mm; 31/2 inch oil pipe is used as drill pipe specimen, of which the diameter is 73.025mm; drilling fluid taken from oil field shall be dosed into density of 1.32

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g/cm³. Cut the oil pipe into 50mm long pieces and cut the casing material into 60mm long pieces. Water base mud used at site will be used for experiment. During processing of specimen, attention shall be paid to processing accuracy. Length of specimens shall be uniform. Ends of drill pipe and casing specimens shall be cut perpendicularly. Damage influencing wear, like scratch, shall be avoided on surface of drill pipe and damage influencing friction shall be avoided on internal surface of casing.

Specimen installation and notices: During process of installation, casing specimen shall be firmly and horizontally fixed with cement and loosing shall not be allowed due to vibration during experiment; otherwise the experiment result will be impacted. Drill pipe specimen shall be fixed onto main shaft at firm position to ensure that wear will be applied on the casing at the same position. Drill pipe shall not be installed inclined; otherwise high vibration will be caused and wear would not be applied on casing at level circumferential position.

Control of experiment force, rotation speed, time and temperature: Apply normal stress with lever force system of frictional wear experiment machine, regulate manually the control panel to reach required rotation speed of drill pipe, preset running time, control the temperature of drill fluid around 20℃ with heater in the corrosion box. Pour drill fluid with density of 1.32 g/cm³ into the corrosion box. Lift the corrosion box to dip the friction pair of drill pipe and casing into the drilling fluid, Start motor of main shaft and regulate rotation speed, making the main shaft driving drill pipe to simulate rotating of drill pipe and contact friction with casing, as well as wearing condition of drill pipe and casing during drilling.

Experiment process: Start the friction wear experiment machine and run it for 10 min. It is found that at the preliminary stage, vibration is high due to friction, of which the main reason is that friction factor and friction force are significant due to inadequate smoothness of external surface of drill pipe specimen and internal surface of casing. Vibration will be reduced after the run-in stage. It is the key point of the experiment to deal with the volume error of wear caused by vibration. Software of the experiment machine calculates wear volume averagely in different time period and the measurement data will be treated manually after completion of experiment. Software measurement data make it possible for researcher to intuitively follow the wearing process. Data transmitted to the computer, including friction force, average friction factor and average wear volume etc., are displayed in the form of curve and text.

**Relation between wear of casing and rotation speed**

When rotary drilling is adopted, increment of rotation speed will reduce axial friction force and accelerate progress of drilling; however, it will also increase the friction route between drill pipe and casing. To optimize rotation speed, influence of rotation speed on final wear volume of casing shall be studied. Maximum allowed wear volume of casing shall be determined according to influence of strata press and sequential work on worn casing. Rotation speed shall be selected by considering multiple factors. In this paper, the experiment is mainly concentrated on studying influence of rotation speed on wearing rate of casing under certain normal stress and within certain time duration, for the purpose of providing reference for anti-wearing design of casing and design of wear course and drilling parameters.

It is shown from the curve of wear volume drawn by experiment machine that at preliminary stage, wear volume increases rapidly with increment of times of rotation due to that the friction pair surface is relatively rough. Surface fineness of specimen is increasing continuously with extending of wearing time. From the view of skimming wear, the surface is deactivated continuously and abrasiveness of drill pipe specimen is reduced, i.e. friction specimen is running-in rapidly with increment of times of rotation. After increasing rotation speed of experiment machine, stability of experiment machine is reduced and vibration of drill pipe and casing in increased, which leads to increment of contact force between drill pipe specimen and casing and increment of wear volume. It is found from the experiment that, with load of 90N, when rotation speed of drill pipe specimen is less than 140r/min, vibration of drill pipe and casing is less; and when rotation speed is higher than 140r/min, resonance will occur to drill pipe and casing with bigger amplitude and higher frequency. Through analysis of result, it is found that when rotation speed exceeds 140r/min, volume of iron scurf caused by vibration has been increased obviously.

Through experiment under constant normal stress, linear relation formula between wear volume of casing specimen V and rotation speed n is obtained as follows:

$$V = 0.008n + 0.2511 \qquad R^2 = 0.9671 \tag{1}$$

In the formula, V, wear volume, mm³; n, rotation speed, r/min⁻¹; R, regression coefficient.

**Analysis of influence of normal stress on wear**

Microscopically analyzed, contact stress is critical for wear of friction pair. Normal press is the source of contact stress between contact faces. It is known from Hertz contact stress formula that the maximum contact stress between static drill pipe and casing is located at middle of contact position. Therefore, wear at middle of contact position is most significant. From definition of wear volume (wear volume is the biggest worn thickness of casing wall), it is known that maximum contact stress is an important standard measuring wear volume. Wear will enlarge contact area between drill pipe and casing and change distribution of contact stress. With increment of contact area, maximum contact stress will be reduced.

At the preliminary stage, contact area between drill pipe and casing is small, maximum contact stress is high and wear rate is high as well. With extending of wearing time, contact area between friction pair increases and maximum contact stress decreases, therefore wear rate decreases as well. Assuming that wall of casing is thick enough, once worn thickness becomes equal to radius of drill pipe, wear rate will not change significantly any more.

Study wear rate with certain rotation speed under different normal stress, measure wear volume of casing specimen within different time duration, and analyze influence of normal stress on wear of casing by comparison.

A lot of data has been obtained through the experiment. According to formula of wear volume and time obtained through regression of experiment data, it is found that when wear volume is small, polynomial relation exists between wear volume and time. Compared with power curve equation, polynomial expresses with higher fitness. It is found in the experiment that at preliminary stage, the casing is worn rapidly; however, wear becomes slower with increment of wear volume until slope of curve reaches constant. When normal stress increases, wearing time of contact face decreases, and relation diagram of wear volume changing with time tend faster to straight line. With stress of 270N, change of wear of casing can be basically deemed linear at middle and later stage. With stress of 340N, vibration of drill pipe and casing becomes severe and wear rate of casing is not complying with that of previous three experiments. Drill pipe and casing are not running-in well due to vibration, and the wear rate is significantly higher than that of other experiments.

Relation of wear volume and time when rotation speed is 120r/min and normal stress is 90N. It is shown that casing is worn with high rate at early stage of wearing, for which the main reason is that with increment of wear volume of casing, contact area between drill pipe specimen and casing increases and maximum contact stress between the friction pair decreases, leading to decrement of wear rate; at beginning, the contact face between drill pipe and casing is relatively rough with high friction factor, and the friction force is strong. However, with run-in of friction pair, friction factor and friction force will decrease; at early stage, vibration amplitude of casing specimen is big, leading to increment of normal stress between contact face. Since vibration reduces real contact time between drill pipe and casing, their influence on wear of casing shall be further studied.

Power relation formula between wear volume of casing specimen and wearing time with rotation speed of 120r/min and normal stress of 90N obtained through the experiment is as follows:

$$L = 0.0031t^{0.5472} \quad R^2 = 0.9784 \tag{2}$$

In the formula, t is wearing time, s.

Relation of wear volume and time when rotation speed is 120r/min and normal stress is 120N. It is found through experiment that reasonable selection of rotation speed and normal stress enables good run-in of friction pair and reduces wear of casing. It is capable of realizing the purpose of reducing wear of casing by optimizing drilling parameters combination by considering working conditions.

Power relation formula of wear of casing and time with rotation speed of 120r/min and normal stress of 120N:

$$L = 0.0084t^{0.4599} \quad R^2 = 0.9665 \tag{3}$$

Relation of wear volume and time when rotation speed is 120r/min and normal stress is 270N. Compared with the experiment applying normal stress of 120N, at early stage, run-in of casing is rapid and wear volume is increasing relatively faster.

Power relation formula of wear of casing and time with rotation speed of 120r/min and normal stress of 270N:

$$L = 0.0026t^{0.6115} \quad R^2 = 0.972 \tag{4}$$

Relation of wear volume and time when rotation speed is 120r/min and normal stress is 360N.

Since applied normal stress is extremely high, the specimens are vibrating severely. Contact force generated by vibration results in that run-in between external surface of drill pipe and internal surface of casing is not good. Change of wear volume is fluctuant increment. In this case, wear mechanism of casing is complicated. At early stage, through observation of iron scurf generated by wear and wear scratch on internal surface of casing, it is found that shape of wear particles is mainly strip and crescent, and wear scratch is furrow. It is determined that type of wear is mainly adhesive wear and furrow wear. It shows that at early stage of wear, since contact stress is great, type of wear is mainly adhesive wear. With increment of wear volume, contact stress between drill pipe and casing decreases, and type of wear becomes furrow wear and abrasive wear.

Power relation formula of wear of casing and time with rotation speed of 120r/min and normal stress of 360N:

$$L = 0.0007t^{0.8888} \quad R^2 = 0.901 \tag{5}$$

**Influence of temperature on wear of casing**

Temperature plays an important role in friction. It can change performance of drill fluid, and even the material characteristics of friction pair surface. There is certain breakthrough temperature for absorption film, exceeding which the absorption film will be peeled off and unidirectional and lubricant will lose efficacy, and frictional factor of friction pair will be further increased. Therefore, down hole temperature shall be simulated in the experiment.

According to experiment design, different temperatures will be applied with other conditioned not changed. It is found that drill fluid is relatively stable below 60℃. Within the range of temperature, influence of temperature on wear of casing is not significant. It is suggested that in future experiment, wear of casing can be studied under temperature higher than 60℃ and influence of heat generated by friction on wear can be studied as well.

**Influence of drill fluid on wear of casing**

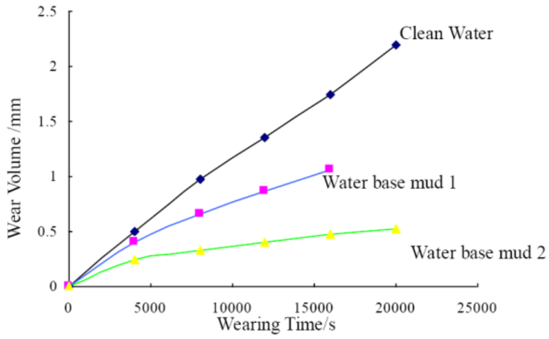


Figure 1. The influence analysis of medium to wear

Improving performance of drill fluid is one of the important methods to reduce wear of casing. For oil base drill fluid, density's influence on lubrication performance is extremely slight; however, oil water ratio has more significant influence on lubrication performance. For example, compared to that of oil water ratio 68:32, friction factor of oil base drill fluid of water ratio 90:10 between metal and metal and metal and sandstone is less by more than 40%. Compared to water base drill fluid, extreme pressure lubricant and anti-seize lubricant improve performance of drill fluid more significantly, since under the extreme pressure condition of relative movement between drill pipe and casing, extreme pressure lubricant forms low melting extreme pressure film on the metal surfaces, which reduces friction factor between drill pipe and casing; anti-seize lubricant interacts with clay in the sandstone and reduces hydration and sticking, which reduces friction factor between drill pipe and openhole cake. Drill fluid plays multiple functions in frictional wear between drill pipe and casing. For studying functions of drill fluid, experimental comparison of wear has been made by using clean water and water base mud of two different viscosities as lubrication medium, under the condition of 90N load and speed of 100r/min. The result is shown in Fig.1. Viscosity of water base mud 1 is lower than that of mud 2. Within the same time duration, wear volume of clean water is higher than that of mud 1, and wear volume of mud 1 is higher than mud 2. Moreover, with lubrication of water base mud 2, friction pair of drill pipe and casing reaches run-in earlier, proving that increment of viscosity of water base mud used in the experiment is beneficial for reducing wear of casing.

## CONCLUSION

Through frictional wear experiment, wear volume of casing with different rotation speed has been analyzed; influence of normal stress on wear volume of casing; comparison of wear volume by using clean water and water base mud of two different viscosities as medium; influence of temperature on wear volume of casing. Following conclusions have been obtained:

When rotation speed is slow, relation of wear volume and rotation speed is linear; when rotation speed is high, wear volume increases severely due to vibration.

Under different normal stresses, relation between wear volume and time is power relation formula or polynomial relation, and fitness of the later is higher than that of the former. Under different normal stresses, wear volume is not proportional to time, and influence of normal stress on wear volume is nolinear.

Water base mud of high viscosity is capable of reducing wear of casing.

Temperature below 60 ℃ has no significant influence on wear of casing.

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