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Study of Mechanical Properties of Shear Ram

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Abstract

In this paper, a double-V structure shear ram blowout preventer is used as the research object, and the three-dimensional models of the shear ram and the drill pipe are established respectively. The Johnson-Cook principal structure model and the Shear Damage ductile fracture criterion are used to simulate the shear ram shearing the drill pipe through the display dynamics module, and the mechanical properties of the ram are analyzed. The shear ram was also used to shear two different sizes of S135 drill pipe, φ127 mm (5 in) and φ139.5 mm (5.5 in), to study its adaptability to different sizes of drill pipe. The results show that the new shear gate can shear two different sizes of S135 drill pipe of φ127mm (5 in) and φ139.5mm (5.5 in) smoothly and has good adaptability. The shear force during the simulation was extracted and compared with the calculated value based on the empirical equation of Mises yield criterion. The mechanical characteristics of the shear ram blowout preventer were investigated, and the adaptability, the variation law of the empirically calculated and simulated calculated values were also discussed, and the reasons for the differences between the empirical and calculated values were analyzed.

Keywords

Shear ram BOP; Johnson-Cook model; mechanical properties; adaptability; numerical simulation.

1. Introduction

In drilling operations, well control equipment is the key equipment to detect and control overflow in time, prevent blowout, avoid waste of oil and gas resources, and protect equipment and personnel safety [1]. Shear gate blowout preventer is one of the most critical well control equipment to deal with emergencies. Its function is to cut off the operating string and seal the well to ensure the safety of ground equipment and personnel. Its working performance is the key to ensure the safe well sealing.

At present, domestic and foreign scholars have put forward many research methods for evaluating shear ram. C.J. Han [2] and X.P. Huang [3] studied the performance of shear ram from the perspective of stress and strain, and obtained the optimal parameters. Y.L. Ye et al [4] analyzed the sealing performance of shear ram. X.D. Zhao et al [5] performed a three-dimensional numerical simulation of the process of shearing drill pipe by a gate plate. X.Y. Meng et al [6] evaluated the shear capacity of marine shear gates. W.Q. Zhao [7] analyzed the shear capacity and application method of deep-water blowout preventer. B. Liu [8,9] analyzed the gate shearing process and the height of the drill pipe projection from the mechanical point of view. P.C. Wang et al[10] established a quantitative evaluation method for shear gates based on vision technology and image processing techniques. X.D. Wang et al[11] developed a prediction model for shear based on the compressive stress equation. Sunghee Kim [12] analyzed the availability of subsea blowout preventer using Markov model. Cai [13] and Liu [14] et al. used dynamic leaf bass networks to study the reliability of the gate blowout preventer control system. Tekin A et al [15] used numerical simulation to predict the shear force. Z.G. Liu[16] used the extended Moore-Coulomb criterion to study the shear force of the gate plate. Y.N. Yang. et al [17] studied the inherent characteristics of the gate anti-sprayer structure. X. He [18] explored the factors of the failure process by building a fault tree of the gate blowout preventer. R.X. Ou et al [19] optimized the well control equipment sealing pressure test method. E.S. Ping [20] studied the temporary remedial measures of hemp fiber soft packing for the gate plate blowout preventer seal failure conditions.

Although experts and scholars at home and abroad have done a lot of research work on well control equipment such as blowout preventers. However, the research on the working performance of the shear gate is not systematic and in-depth enough, and the comparison between the calculated and simulated values of the shear force and its variation law still need to be further explored. Therefore, this paper will carry out a relevant study based on this basis.

2. Shear ram working principle

The shear ram is generally composed of two parts. In the event of an emergency during drilling, the upper and lower plates move toward the center of the wellhead and cut the drill pipe under the push of the hydraulic actuator, after which the two parts continue to come together and complete the sealing of the well.

This analysis of the shear ram is shown in Fig 1. The size of the ram is mapped and modeled in three dimensions, and the kinetics module is used to display the analysis, which can better simulate the process of the gate shearing the drill pipe, predict the fracture pattern of the drill pipe and analyze its shear performance.

(a) Upper gate plate (b) Lower gate plate

Fig 1 Physical diagram of shear gate

3. Selection of material models

The Johnson-Cook principal structure model is widely used in the field of metal cutting because it has a good prediction of the strength limit and failure process of metal materials under large strain, high strain rate and high temperature environment. The process of shearing drill pipe is accompanied by large deformation and high strain rate, so the Johnson-Cook principal structure model is used, and the specific expressions are as follows.

$$\sigma = (A + B\varepsilon^{n})(1 + C\ln\dot{\varepsilon}^{*})(1 - (T^{*})^{m}) \tag{1}$$

$$\dot{\varepsilon}^{*} = \dot{\varepsilon} / \dot{\varepsilon}_{0} \tag{2}$$

$$T^{*} = (T - T_{0}) / (T_{m} - T_{0}) \tag{3}$$

in the formula A, B, C, m, and n are material parameters; σ is Mises stress, MPa; $\dot{\varepsilon}$ is equivalent plastic strain; ε^{*} is plastic strain rate; ε_0 is reference strain rate; T^{*} is homologous temperature; T_m is melting temperature; T_0 is room temperature; T is the instantaneous temperature of the material during deformation.

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The Johnson-Cook model parameters for the S135 drill pipe material, as shown in Table 1.

Table 1 Parameters of Johnson-Cook model for S135 drill pipe

A/MPa	B/MPa	n	C	$\dot{\varepsilon}_0 / s^{-1}$	m
937	760	0.25	0.01	1	0

Shear Damage is based on the equivalent plastic strain at the unit integration point to determine the failure, and the unit is considered to fail when the equivalent plastic strain reaches the threshold value and the unit is deleted. The Shear Damage ductile fracture criterion [21] is chosen because of its good results in predicting fracture quality, and the specific expression is as follows.

$$C_{sf}=(\varepsilon_0+\sum\Delta\gamma)/\varepsilon_f \tag{4}$$

C_{sf} is the fracture critical judgment value; ε_0 is the initial equivalent plastic strain; $\Delta\gamma$ is the equivalent plastic strain increment; ε_f is the equivalent plastic strain at fracture. The plastic strain is generated when C_{sf} =1, which ε_f varies for different materials, and according to the literature [3], the plastic strain at fracture ε_f=0.2.

4. Finite element modeling

The three-dimensional models of the ram and the drill pipe were established separately, and the shear part of the drill pipe and the edge part of the gate were cut by neglecting the factors that had no effect on the shear performance, such as the sealant core, the thread and the round hole away from the edge. The gate material is 40CrNiMo and the drill pipe material is 36CrNiMo4A. The material properties are shown in Table 2. The grid division results are shown in Fig 2.

Table 2 Mechanical properties of materials

Category	Materials	Yield strength /MPa	Tensile strength /MPa	Elastic modulus /MPa	Poisson's ratio
Shear ram	40CrNiMo	960	1050	2.10×10^5	0.295
S135 drill pipe	36CrNiMo4A	937	976	2.02×10^5	0.300

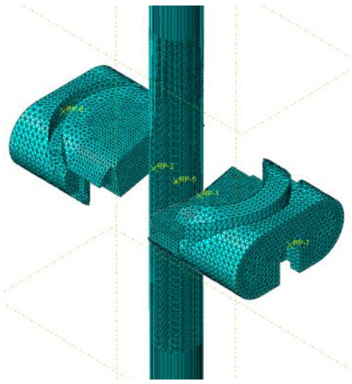


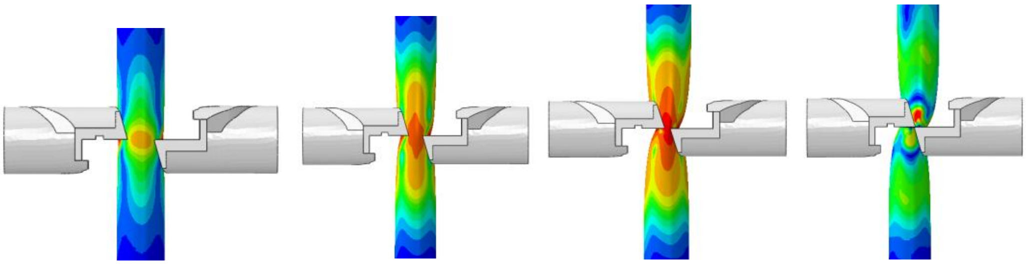
Fig 2 Grid division results

The ram plate is meshed with C3D4 tetrahedral cells and the drill pipe is meshed with C3D8R hexahedral cells. In order to improve the calculation accuracy and reduce the calculation time, only the shear part of the drill pipe and the edge part of the gate plate are meshed. Constrain the translational freedom of the upper face of the drill pipe in the xy direction, and keep the lower end of the drill pipe free. There is a 1mm gap between the upper and lower rams, and the gates are set as discrete rigid bodies and constrained by reference points on the back. The coefficient of friction is chosen as the common friction coefficient between steel and steel 0.15. The velocity in the x-direction is 20 mm/s applied at the reference point, and the velocity of the upper and lower gates is in opposite directions.

5. Shearing process and fracture morphology analysis

5.1. Analysis of the shearing process

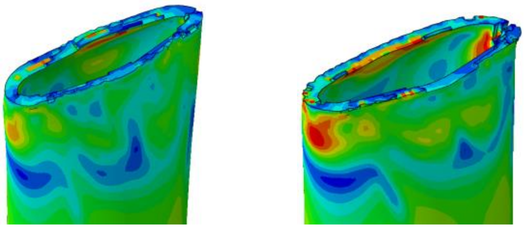
The movement process of the gate plate shearing the drill pipe can be divided into four stages: contact, extrusion, plastic deformation and fracture, as shown in Fig 3. The gate plate first touches the drill pipe, and stress concentration occurs at the contact position, after which the drill pipe is continuously squeezed to produce elastic deformation, and with further squeezing of the gate plate, the drill pipe enters the plastic deformation stage, after which the gate plate continues to close together and finally shears the drill pipe to complete shearing. At the same time, the double gate structure can not only improve the shearing force, but also the V-shaped structure of the gate helps the automatic centering of the drill pipe.



(a) Contact (b) Squeeze (c) Plastic deformation (d) Fracture

Fig. 3 The shearing process of the upper straight down V-shaped gate

5.2. Fracture morphology analysis



(a) Upper half of drill pipe (b) Lower half of drill pipe

Fig 4 Drill pipe fracture morphology

The shape of the fracture of the drill pipe after shearing is completed is shown in Fig 4. The shape of the fracture of the two types of drill pipes is roughly equivalent, and the upper and lower parts are compressed in a flatter diamond shape, with stress concentration at the fracture, and the stress concentration area of the lower part of the drill pipe fracture is larger and the fracture is not flat. Since this kind of gate plate leaves space to accommodate the sheared drill pipe, after the drill pipe is sheared, it will push the drill pipe to the space on both sides due to the continued forward movement of the gate plate.

6. Comparison analysis between simulated and empirical values

The maximum shear force required to shear the S135 drill pipe with a wall thickness of 9.19 mm at φ127 mm (5 in) is 1.10×10^3 kN, and the maximum shear force required to shear the S135 drill pipe with a wall thickness of 10.54 mm at φ139.5 mm (5.5 in) is 1.41×10^3 kN. The simulated

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values are compared with the calculated values from the empirical equation [22] (5) , the results of which are shown in Table 3 and Fig 5.

$$F = \frac{\pi}{\sqrt{3}} \sigma_s \left(R^2 - r^2 \right) \tag{5}$$

Where: F is the shear force, kN; σ_s is the material yield limit, MPa; R is the outer diameter of drill pipe, mm; r is the inner diameter of drill pipe, mm.

Table 3 Comparison of results

S135 drill pipe	Wall thickness /mm	Simulation value /kN	Calculated value of empirical equation (5)/kN	Impact factor C
φ127mm (5 in)	9.19	1.10×10^3	1.84×10^3	0.598
φ139.5mm (5.5 in)	10.54	1.41×10^3	2.31×10^3	0.610

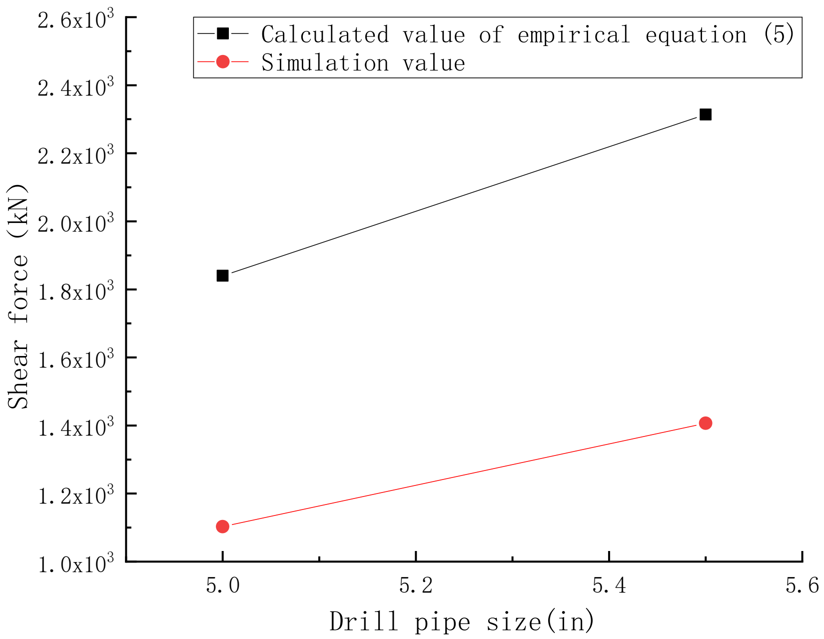

Fig 5 Comparison of formula value and simulation value

As can be seen from Table 3 and Figure 5, the shear force generally tends to increase as the cross-sectional area of the drill pipe increases. The calculated value of the empirical equation used is relatively conservative, which makes the shear gate have the ability of super shear to ensure that the drill pipe can be sheared smoothly. The value of the empirical formula (5) is slightly larger than the simulated value; the calculated value of formula (5) still has a certain error with the simulated value for two reasons: one is the introduction of Mises yield criterion itself has a certain error; the second is that the empirical formula does not take into account the impact of the knife type on the shear force. Therefore, when the empirical formula is used, the correction parameters can be appropriately selected to correct it.

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7. Conclusion

1. The shearing process includes four processes: contact, extrusion, plastic deformation and final shearing. The use of the upper and lower double gate form helps to improve the shearing performance, and the V-shaped structure of the gate is conducive to the automatic return of the drill pipe to the center.

2. The double V-shaped ram plate has good adaptability to different drill pipes and can shear different sizes of drill pipes. After the shearing is completed, the drill pipe is pushed to both sides and the shutdown is completed at the same time.

3, The calculated value of empirical equation (5) is greater than the simulated value, and the gate shear test also confirms the conclusion. This is mainly due to the fact that the effect of cutter type on the gate shear force is not considered, and the empirical equation (5) introduces the Mises yield criterion itself with some error.

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