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Experimental study the collapse failure mechanism of cemented casing under non-uniform load

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ABSTRACT

Under non-uniform in-situ stress, the casing collapse failure often happens easily, and especially in soft rock the problem is more serious. In addition, only the few scholars do some studies about failure mechanism of cemented casing under non-uniform in-situ stress which has a strong effect on collapse properties of cemented casing, especially testing investigation. Hence, the collapsing test was performed for cemented casing under non-uniform load (NFL) by adopting self-developed testing equipment, by which the radial deformation of cemented casing and damage rules of cement sheath have been measured and the stress-strain laws of cemented casing are obtained during the testing process by the electrical method. The initial yield load and plastic limit load of cemented casing as well as the subsequent yield load have been obtained. By analyzing testing data, the stress-hardening rate and strain-hardening rate after hardening have been determined. The effects of cement sheath on collapse properties of P110SS casing and strain and deformation laws of P110SS casing after hardening have been obtained. The hardening character and failure mechanism of cemented casing have been figured out under NFL.

1. Introduction

Cement sheath is located in the annular space between borehole and casing and formed in the cementing process. It can decrease the load applied on the casing from surrounding rock, and improve the stress distribution and collapse properties of casing so that it plays a paramount importance role in protecting casing collapse failure and wellbore integrity, isolating oil, gas, water and restricting different types of complicated stratum during drilling and production [1–2].

Hence, in order to find out the failure mechanism of cemented casing and wellbore integrity, lots of studies focused attention to failure mechanism of cemented casing under uniform external pressure and wellbore integrity have been done by scholars [3–10] in recent years, and many important achievements have been obtained. For instance, based on finite element method, Karen and Schubert et al. [11–12] have simulated the collapse load applied on cemented casing and analyzed the effect of mechanical properties of cement sheath on the collapse load of casing under uniform external load, and researches results indicate that

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the cement sheath and its mechanical properties have a great impact on the collapse failure mechanism of casing. Gao Deli and Beck et al. [13–14] have obtained stress distribution of cemented casing and analyzed the influence of cement sheath and cementing quality on casing failure mechanism.

However, for the NFL, only a limited number of scholars have carried out studies about casing failure mechanism [15–18], particularly the failure mechanism of cemented casing, and most of those studies are only in theory [19–23]. The theoretical studies [24] on failure mechanism of casing alone (without consideration of the cement sheath) under NFL show that the NFL will decrease collapse properties of casing obviously (especially the opposed line load [25]), leading to casing failure easily.

It can be conclude that the NFL and cement sheath have a great impact on the collapse properties of casing, and the study on the casing failure mechanism is not enough under NFL, particularly the testing study on cemented casing. Hence, based on the achievements of this work group [26–27], this paper has performed the collapsing test of cement casing under NFL, and investigates its failure mechanism.

2. Main testing equipment and program

Based on the achievements of this work group [26–27], one collapsing test of cemented casing (it is composed of inner pipe, cement sheath and outer pipe.) is conducted under NFL by adopting the same testing method proposed by the literature [27]. Table 1 is the related parameters of cemented casing. In Table 1, the inner pipe (P110SS casing) is the research object, and the outer pipe is J55 casing and used to simulate the stratum. The testing equipment of cemented casing is shown in Fig. 1. The static strain indicator and the pressure testing machine are used to measure the strain on the cemented casing and the radial deformation of cemented casing under different external load during the testing process, respectively.

The strain gauges and special wires are placed into square grooves on both sides of J55 casing (outer pipe), and the positions of all the strain gauges adhered on the surface of inner pipe (P110SS casing) of cemented casing are shown in Fig. 2.

3. Testing results of cemented casing under NFL

3.1. Radial deformation analysis

To get the accurate test data (strain, stress and radial displacement under different external load), the loading method presented by the literature [27] is adopted in this paper. The loading process of the cemented P110SS casing is 50 t → 60 t → 70 t → 80 t → 90 t → 100 t → 65 t → 120 t → 125 t → 145 t → 140 t → 148 t → 150 t. The radial deformation during loading process and plastic displacement (residual deformation) after completely unloading are shown in Table 2 and Fig. 3.

Fig. 3 shows that the loading process of cemented casing involves three typical stages (elastic, hardening and instability). The cemented casing (P110SS) obviously stays in the elastic deformation when the NFL is <70 t. From Fig. 3 and Table 2, it is interesting that the plastic displacements of cemented casing have reached 0.4 mm and 0.8 mm, respectively, in this loading process (60 t and 70 t), though the cemented casing still stays in the elastic deformation. In contrast, the cemented casing (P110SS) starts to yield until the NFL is >70 t, as well as the radial deformation and plastic displacement increase with the increasing NFL, which indicates that the cement sheath around the P110SS casing has a great impact on the collapse failure mechanism of casing under NFL. The plastic displacements (0.4 mm and 0.8 mm) of cemented casing might be the total compaction of cement sheath between inner pipe (P110SS casing) and outer pipe (J55 casing), which needs to be demonstrated further by stress-strain analysis. In addition, the further analysis of strain and deformation laws of cemented casing should be done for determining yield load accurately.

The radial deformation of cemented casing increases slowly when the NFL is <100 t. However, the radial deformation increases sharply when the NFL is >100 t. As a result, it can be inferred that the cemented casing always stays in hardening stage when the NFL is smaller than 100 t, and the structural instability of cemented casing might happen or has happened when the NFL is >100 t. Hence, it is indispensable to study the stress-strain law of cemented casing for determining the instability load in detail.

Finally, with the NFL reaching up to 150 t, the corresponding radial deformation and plastic displacement are 46.0 mm and 28.8 mm respectively. The damage morphologies of cemented sheath are shown in Fig. 4. The damage of cement sheath at the deformation section of cemented casing is very serious so that the cement-sheath integrity has been damaged completely, as shown in Fig. 4(a), while the cement sheath at both ends of cemented casing almost has no damage except a few small cracks, as shown in Fig. 4(b).

Table 1
Related parameters of cemented casing.

Casing type	Length (mm)	Thickness (mm)	OD (mm)	Yield strength (MPs)	Tensile strength (MPa)	Thickness of cement sheath (mm)
P110SS (inner pipe)	1000	11.50	178.0	860	936	24.3
J55 (outer pipe)	1000	8.94	244.5	380	–	