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Research article

An experimental study on reshaping C110 deformed casing with spinning casing swage

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Abstract

Casing deformation affects the implementation of stimulation and development measures of oilfields directly; however, the reshaping force and torque usually are determined by experience when the deformed casing is repaired with the spinning reshaping technology; if the repairing force or torque is too large, it will result in the damage of casing and cement sheath as well as sticking accident. So, the collapse experiments were performed on the YAW-200 pressure testing machine by using one production casing which is often used in the oilfield and then the reshaping test of deformed casing (C110) was performed in turn by using two spinning casing swages of which the diameter is 126 mm and 129 mm respectively. The continuous rotator and thrust bearing were used to provide the torque and reshaping force respectively in the repairing process. The reshaping force and torque required to reshape the deformed casing, the deformation law and the springback value of deformed casing were obtained. Test results show that the diameter differential between the two spinning casing swages is reasonable. Furthermore, in order to ensure the safety and reliability of the implementation of post-production technologies, the mechanical properties of deformed casing before and after reshaping were tested. It was found that all the mechanical parameters of the deformed casing after reshaping reduced, which resulted in the decrease of the strength of the reshaped casing. These research achievements would provide important experimental data in optimizing the structure and construction parameters of spinning casing swages.

Keywords: Spinning casing swage; Reshaping test; Reshaping force; Deformation; C110 casing

1. Introduction

Casings in many oil and gas wells at home and abroad would have deformation [1,2] after production for a period of time due to the effects of geology, engineering, and corrosion, especially in formations prone to collapse, or with plastic creep or poor cementing quality [3–5], which poses a serious threat to the safety and benefits of oil and gas fields. For example, the casings in Well Longgang 001-1, Longgang 001-2, Longgang 39, Longgang 13 in Chongqing-Sichuan oilfield, and TK1127 in Tahe oilfield in Xinjiang province were all deformed due to creep and plastic flow of salt rock. Statistics show that wells with casing damage amount to more than 10 thousand in China, hence, casing repair technology is more and more important in the middle and late stage of oilfield development.

As to repairing the deformed casings, many repair technologies [6,7] have been developed at home and abroad. It is found from comparing these technologies that the spinning reshaping technology has the advantages of small reshaping force, low requirement on the strength of drill string, and small

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damage to the deformed casing, which makes it an efficient mechanical reshaping technology. However, the current spinning reshaping technology could end up in failure [8−10] (for example, too small reshaping force can not reach the purpose of repairing, and too big repairing force could cause severe damage to cement sheath and secondary damage to casing as well as sticking accidents) due to lack of accurate control of the reshaping force and torque. To date, researches on the failure mechanisms of casing [11], casing failure detection technologies [12,13], casing repair technologies [14−18], and preventive measures [19] have been fruitful, especially theoretical and experimental study on the solid expandable tubular repair technologies [20−22].

However, the theoretical and experimental study on the spinning reshaping technology is deficient. Only Jiang [23] studied the repair process of spinning reshaping by establishing a mechanical model based on the Hertz contact mechanics, which could provide some theoretical reference for spinning reshaping technology, but the theoretical study is short of experimental validation. As a result, the reshaping force of spinning reshaping technology can only be estimated from experience on site with some randomness, which can easily lead to secondary damage to casing and cement sheath and even sticking accidents.

In conclusion, it can be seen that many previous studies focus on failure mechanisms of casing, casing repair technology, and casing failure detection technology [24], in contrast, the experimental study on spinning reshaping technology is deficient, especially on the reshaping force and torque. In addition, stimulation treatments (such as fracturing and acidizing) are directly applied to repair wells in oil and gas fields in the late stage of development without consideration of the effect of mechanical plastic repair on the deformed casing, which could lead to serious accidents. Hence, the reshaping test of deformed casings (C110) has been performed by using spinning casing swages, and the mechanical properties of deformed casing before and after repair have been analyzed and evaluated in the study. The testing results can provide relevant guidance for optimizing the structure and construction parameters of spinning casing swages. Meanwhile, the research achievements can provide important experimental data for stimulation treatments in repaired wells.

2. Working principle of spinning casing swage

2.1. Basic structure

The spinning casing swage mainly consists of a guide cone, a workspace, and a controlling end; the cone angle of spinning casing swage is 12°. There are several parallel grooves along the axial direction of spinning casing swage with steel a ball

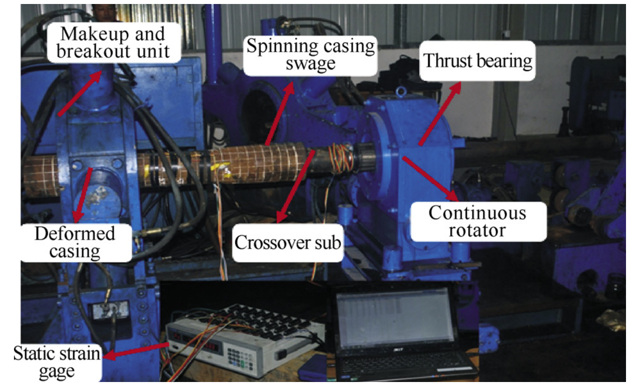

Fig. 1. Experimental apparatus of reshaping test.

(about 30 mm in diameter) embedded in it. The steel ball can not only rotate itself, but also orbit along the axis of the spinning casing swage.

2.2. Working principle under actual working condition

The steel ball will rotate itself and orbit along the axis of the spinning casing swage when certain axial force and torque are applied to the spinning casing swage by the drill string. The spinning reshaping primarily depends on the high contact stress produced by the steel ball rolling over and over again at the deformation position of casing to achieve the repairing purpose.

2.3. Experimental apparatus and method

There were two stages in the reshaping testing: one is preparation stage of a oval casing, in which a piece of production casing (C110 × Φ177.8 mm × 12.64 mm) was pressed on the YAW-2000 pressure testing machine, and the final deformed size of the casing was determined based on the deformation data of casing in oilfields, as is shown in Table 1; the other is the reshaping test stage of the deformed casing by using two spinning casing swages with 126 mm and 129 mm in diameter respectively, as is shown in Fig. 1.

The experimental apparatus mainly consisted of a makeup and breakout unit, a continuous rotator, a thrust bearing, a YE-2533 static strain gage, a crossover sub and a micrometer. The makeup and breakout unit was used to fix the deformed casing; continuous rotator and thrust bearing were used to apply continuous reshaping force and torque, respectively, to make the spinning casing swage do axial movement and rotation in the center of the deformed casing; static strain gage was used to measure the compressive strain on the crossover sub and the deformation rule of deformed casing during the repairing process; the micrometer was used to measure the radial

Table 1
Geometric and mechanical parameters of the C110 casing before and after deformation.

Type	Long axis inner diameter/mm	Short axis inner diameter/mm	Wall thickness/mm	Axial length/mm
Before deformation	177.8	177.8	12.64	1000
After deformation	186.4	118.6	12.65	1000

displacement of the deformed casing after repair. Hence, the repairing effect of the deformed casing can be figured out according to the deformation rule and radial displacement of the deformed casing after repair. Finally, based on the Hook's law, geometric dimension and compressive strain of crossover sub, the reshaping force can be worked out.

3. Reshaping test of deformed casing

3.1. Test results and analysis

3.1.1. Test results and analysis of spinning casing swage with 126 mm in outer diameter

It can be seen from Fig. 2 that there was no obvious scratch, damage and disintegration on the spinning casing swage after repair. In order to analyze the repairing effect of the spinning casing swage, the strain on the deformed casing and crossover sub were measured by the static strain gage in the repairing process, and three relation curves were plotted according to the measured strain: the first curve reflects the relationship between the strain on the deformed casing and the repairing time, as is shown in Fig. 3; the second curve reflects the relationship between the reshaping force and the repairing time, as is shown in Fig. 4(a); the third curve reflects the relationship between the torque and the repairing time, as is shown in Fig. 4(b).

Fig. 2. Appearance of the spinning casing swage after repairing.

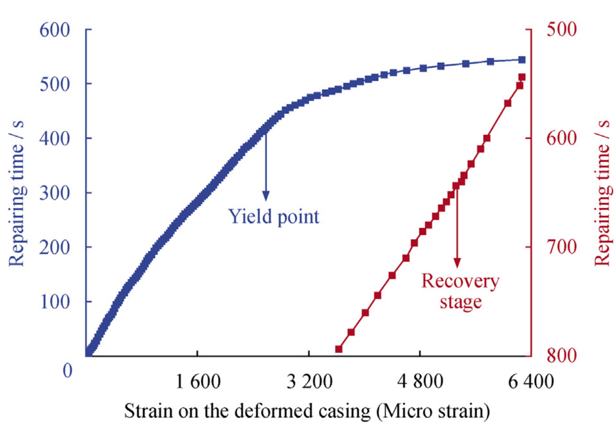

Fig. 3. Relationship between repairing time and strain on the deformed casing repaired by the 126 mm spinning casing swage.

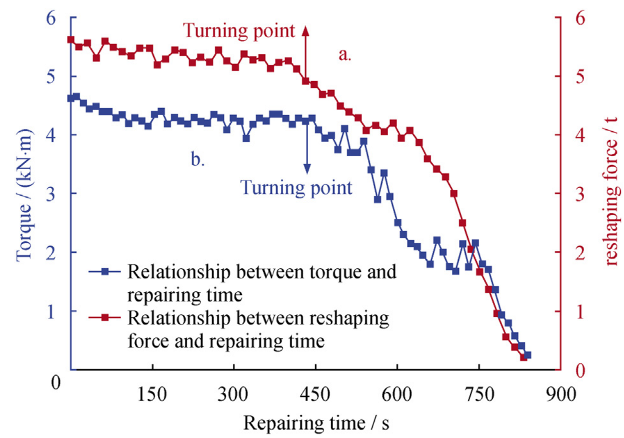

Fig. 4. Relationship between the reshaping force and the repairing time by the 126 mm spinning casing swage.

The deformed casing underwent elastic stage, yield stage and recovery stage in the repairing process, as is shown in Fig. 3. It can be seen that the deformed casing yielded when the repairing time was 420 s; larger plastic deformation of deformed casing happened, and residual strain was produced after repairing. The minimum inner diameter of deformed casing measured by the micrometer was 121.6 mm after repairing, 3.00 mm bigger than the initial inner diameter (118.6 mm), which indicates that good repairing effect has been achieved.

It can be seen from Fig. 4(a) that the reshaping force remained maximum and unchanged basically before the repairing time reached 420 s in the repairing process, indicating no yield of the deformed casing, during this period the maximum reshaping force was 5.75 t. When repairing time extended over 420 s, larger plastic deformation happened to the deformed casing. As the inner diameter of the casing expanded, the reshaping force decreased gradually to 0.2065 t, as is shown in Fig. 4(a), which shows that the reshaping with the swage reaches the expected goal.

Similarly, it can be known from Fig. 4(b) that the torque remained maximum and unchanged basically when the repairing time was less than 420 s in the repairing process, indicating that the deformed casing did not yield, so the axial force needed was large, which is consistent with the deformation pattern during the reshaping of deformed casings. It can also be seen from Fig. 4(b) that the maximum torque was 4.65 kN m. Large plastic deformation happened to the deformed casing, leading to constant expansion of the casing, and gradual decrease of torque needed to 0.4057 kN m when the repairing time exceeded 420 s as is shown in Fig. 4(b). All these also show the reshaping of the deformed casing has achieved the expected result.

Finally, it can be known from Figs. 3 and 4 that the required reshaping force and torque are closely related to the deformation state of the repaired casing. In other words, when the deformation of the repaired casing is in elastic deformation, the reshaping force and torque required are both large and basically constant; after the repaired casing starts plastic deformation, the reshaping force and torque decrease gradually with the increase of repairing time.

3.1.2. Test results and analysis of spinning casing swage with 129 mm in outer diameter

The maximum outer diameter of the spinning swage in the experiment was 129 mm. The deformed casing has a minimum inner diameter of 121.6 mm (the reshaped casing with the 126 mm spinning swage). Similarly, three relationship curves were plotted based on the measured strain. The first curve shows the relationship between the strain on the deformed casing and repairing time, as is shown in Fig. 5; the second curve shows the relationship between the reshaping force and repairing time, as is shown in Fig. 6(a); the third curve shows the relationship between the torque and repairing time, as is shown in Fig. 6(b).

It can be seen from Fig. 5 that the deformed casing yielded at the repairing time of about 400 s; then large plastic deformation happened to the deformed casing, and large residual deformation was produced after repairing. The minimum inner diameter of the deformed casing after repair measured by the micrometer was 124.4 mm, 2.80 mm larger than the initial inner diameter (121.6 mm), which indicates that the deformed casing has been reshaped.

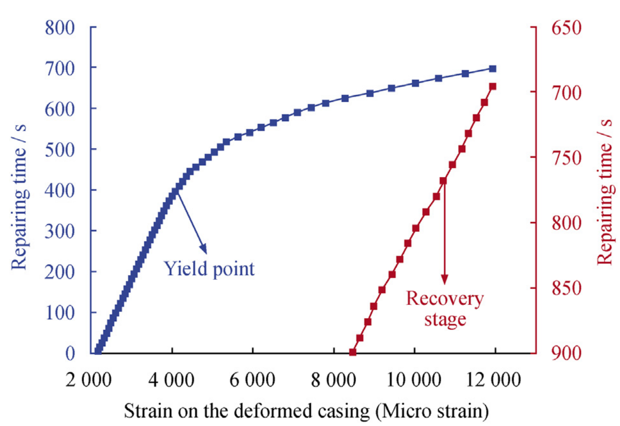

Fig. 5. Relationship between repairing time and strain on the deformed casing repaired by the 129 mm spinning swage.

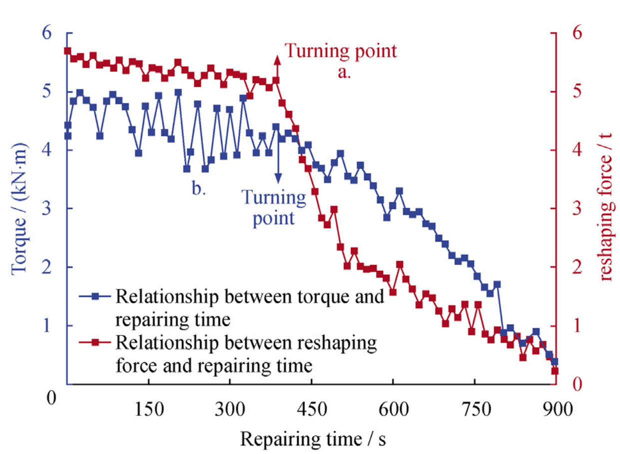

Fig. 6. Relationship between the reshaping force and repairing time by the 129 mm spinning casing swage.

It can be seen from Fig. 6 that the reshaping force remained maximum and unchanged basically before the repairing time reached 400 s in the repairing process, which in combination with Fig. 5 shows that the deformed casing did not yield before the repairing time reached 400 s. It can be known from Fig. 6 that the maximum reshaping force and torque were 5.72 t and 4.98 kN m respectively. After the repairing time reached 400 s, larger plastic deformation occurred to the deformed casing, and the casing expanded, so the reshaping force and torque decreased with the increase of repairing time gradually until the repairing force reduced to minimum, as is shown in Fig. 6. All the above facts show that the reshaping was satisfactory.

By analyzing Figs. 5 and 6, it can be known that the required reshaping force and torque are closely related to the deformation state of the repaired casing. In other words, when the deformation of the repaired casing is in elastic deformation, the reshaping force and torque required to repair the deformed casing remain high and unchanged; when the repaired casing starts to deform plastically, the reshaping force and torque decrease gradually with the increase of repairing time.

3.2. Analysis and discussion

The above test results show the repairing mechanism of spinning casing swage clearly: the contact stress between the spinning casing swage and the inner wall of the deformed casing is produced by squeezing each other, and the contact stress gradually increases under the push of the thrust bearing. The deformed casing undergoes elastic deformation, yield deformation and large plastic deformation under the effect of contact stress. In addition, the torque makes plastic deformation of the inner wall of the deformed casing uniform, avoiding stress concentration, as a result, the torque and reshaping force work together to repair the deformed casing uniformly.

It can be known from the testing results in Table 2 that the reshaping force and torque required to repair the deformed casing as well as the expanded radial displacement and springback value of the two swages are nearly equal, which indicates that the diameter differential of the two spinning casing swages is reasonable. In addition, it can be seen from Table 2 that significant springback of deformed casing after repair is inevitable, so the effect of springback on deformed casing repair by spinning casing swage should be taken into account in the repairing process.

4. Evaluation of casing mechanical properties before and after repair

4.1. Evaluation of tensile property before and after repair

Test equipment used in this experiment was MTS tensile testing machine. The stress–strain curves before and after casing repair were obtained (the tensile specimens before and after repair were taken from the same position and direction of

Table 2
Test results of the two spinning casing swages.

Diameter of SCS/mm	MID of deformed casing/mm	MID of deformed casing after repair/mm	ERD/mm	Springback value/mm	Reshaping force/t	Torque/(kN·m)
126	118.6	121.6	3.0	4.4	5.75	4.65
129	121.6	124.4	2.8	4.6	5.72	4.98

SCS stands for spinning casing swage; MID stands for the minimum inner diameter; ERD stands for expanded radial displacement.

Table 3
Tensile properties of C110 casing before and after repair.

Specimen	No.	Tensile strength/MPa	Average/ksi	Yield strength/MPa	Average/ksi	Yield ratio	Elongation after break	Average
Before repair	01	918	134	860	125.6	0.93	11.67%	11.41%
	02	944		881		0.93	11.15%	
After repair	01	878	129.3	887	128.9	0.93	10.92%	10.91%
	02	906		891		0.91	10.65%	

the casing, i.e., the deformed position in the longitudinal direction of the casing). The tensile property of the casing before and after repair is shown in Table 3.

It can be seen from Table 3 that the tensile strength, yield strength, and elongation after break of the casing after repair are all lower than those before repair. The calculation shows that the tensile strength decreased by 6.5%; the elongation by 5.0%; and the yield strength by 9.7%.

4.2. Evaluation of the casing hardness before and after repair

A 10 mm thick ring specimen was taken from the central part of C110 casing before and after repair, then both ends of the ring specimen were polished, and Brinell hardness tester was used to measure the hardness of the specimen. The measured hardness values are shown in Table 4.

Table 4 shows that the hardness of casing before and after repair was essentially the same, which indicates that the casing repair has little effect on the hardness of casing.

Table 4
HBW measurement results.

No.	Before	Average	After	Average
1	266.3	271.3	276.3	279.3
	276.3		282.3	
2	270.9	270.9	275.0	276.6
	270.9		278.3	

Table 5
Size and feature of testing materials.

Type of specimen	Number of specimen	No.	Specimen size	Notch type
C110 before reshaping	2	1	55 mm × 10 mm × 10 mm	V
		2		
C110 after reshaping	2	1	55 mm × 10 mm × 10 mm	V
		2		

4.3. Evaluation of casing fracture toughness before and after repair

The test instrument used in this experiment was ZBC2302-D Charpy instrumented impact testing machine, with an impact velocity of 5.24 m/s. The size of Charpy impact specimen with V-notch (sampling along the longitudinal direction of casing) is shown in Table 5. The Charpy instrumented impact testing of casing was performed at 25 °C according to the national standard (*Steel Charpy V-notch Pendulum Impact Test Instrumented and Test Methods*), to obtain the force-displacement curve and energy-displacement curve in the testing process.

The Charpy instrumented impact testing results of C110 casing samples at room temperature (25 °C) are shown in Table 6.

Comparison of the testing results before repair and after repair shows that the impact energy (the total energy) decreased by 24.71%, the average value of maximum force by 0.92%, and the crack initiation energy by 66.36%.

4.4. Brief summary

Table 4 shows that the tensile strength, yield strength and elongation rate of the casing after repair decrease, and the hardness increases slightly. It is known from calculation that

Table 6
Parameters of the instrumented impact testing results.

Specimen	No.	W_t/J	S_t/mm	F_m/kN	S_m/mm	F_{gy}/kN	S_{gy}/mm	W_m/J
Before reshaping	1	212.33	27.40	21.45	5.441	17.08	0.877	97.19
	2	219.97	25.53	23.03	5.475	17.07	0.846	102.10
	Average	216.15	26.46	22.24	5.458	17.07	0.861	99.65
After reshaping	1	165.09	16.95	22.64	2.362	19.20	0.929	38.11
	2	160.38	20.67	21.43	1.944	18.31	0.877	28.92
	Average	162.73	18.81	22.035	2.153	18.755	0.903	33.515

the tensile strength decreases by 3.5%; the yield strength by 2.6% and the elongation rate by 5.8%, while the hardness of casing by 2.5%. The slight increase in hardness indicates that the casing reshaping has little influence on hardness. Table 6 shows the impact energy decreases by 24.71%, the average value of maximum force by 0.92%, and the crack initiation energy by 66.36%.

5. Conclusions

(1) The reshaping tests on C110 deformed casing by using two spinning casing swages with 126 mm and 129 mm in diameter respectively were made to get the reshaping force and torque required for repairing the deformed casing, as well as the deformation pattern and springback of the deformed casing. The swages after reshaping had no obvious scratch, damage and disintegration. Comparison of the results of the two spinning casing swages shows that their diameter differential is reasonable. The testing results can provide relevant guidance for casing repair by using spinning casing swages in the actual working conditions.

(2) The deformed casing undergoes elastic stage, yield stage and recovery stage in the repairing process. Reshaping force and torque required for repairing the deformed casing in the elastic stage are the maximum, which decrease gradually when plastic deformation starts. The springback value of casing after repair is substantial, so it should be taken into consideration in actual operation.

(3) Tensile testing results show that the tensile strength of the reshaped casing decreases by 6.57%; elongation rate by 5.8%, and the yield strength by 9.2% after repair. Fracture toughness testing results show that the impact energy reduces by 24.71%, the average value of maximum force by 0.92% and the crack initiation energy by 66.36%, which suggests that all the mechanical parameters of the casing decrease after repair. As a result, the bearing capacity of casing after repair decreases; therefore, the effect of mechanical reshaping on mechanical properties of casing should be taken into consideration when stimulation treatments are applied to wells with reshaped casings.

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