The Tribological Properties of the Hot-extrusion Nylon Coating in the Oil Well Environment *

MO Yi-min PAN Yun-ping WANG Xiu-mei
Wuhan University of Technology
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Abstract: *The friction and wear properties of the nylon coating, prepared by hot-extrusion, used to protect the surface of the flexible continuous sucker rod were studied by using a pin-on-disc wear tester in the simulated oil well environment. The effects of sliding speed and load were considered. The wear mechanism was also studied by using a scanning electron microscope (SEM). The result shows that the friction coefficients of both kinds of materials, JKPA and ZZ7024B, used to protect the surface of the flexible continuous sucker rod decrease with sliding speed increase, but change little with load increase in the simulated oil well environment. The value of friction coefficient of ZZ7024B is smaller than that of JKPA. The minimum value of friction coefficient of ZZ7024B is about 0.05. The wear volume of ZZ7024B is smaller than that of JKPA under the same conditions of experimentation.*
Key words: *the flexible continuous sucker rod; surface protection; nylon coating; friction and wear; wear mechanism*

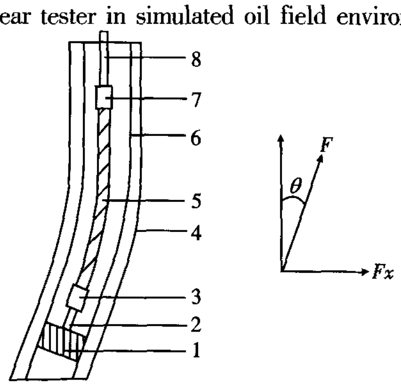
1 Introduction

Mechanical oil extraction is the primary manner of oil extraction throughout the world. About 90% of the oil wells use machine to exploit petroleum in the world, about 80% - 85% employ sucker rod. In china, about 90% of the oil wells use sucker rod. A new type of petroleum equipment, the flexible continuous sucker rod, has a very promising application prospect, because it can fully exhibit its unique excellence over machine oil extraction. Compared with the conventional steel compound sucker rod, it has some outstanding properties, including enhancing the reliability of the sucker rod, reducing incidents under the oil wells, curtailing the pump-inspection time and expenses, boosting oil extraction efficiency, being suitable for denser oil wells as well as tilted and directional oil wells, and exhibiting excellent physical properties. So it is very useful for developing china petroleum industry on land[1].

In China, the depth of oil wells is about 1500m, and the slope of oil wells is about 1‰. The sucker-rod moves in oil well in curves. There is very severe mechanical wear between the sucker rod and the inner wall of pipe when the sucker rod pumps in the tubing, especially in tilted or directional oil wells. In Fig. 1, when the sucker rod works, the force $\vec{F}$ on the sucker rod will have a horizontal component $\vec{F}_x$. Owing to the horizontal $\vec{F}_x$, there is a very severe sliding friction when the sucker rod contacts the wall of the tubing with each other. A supporting-instrument was used to reduce the friction and wear between the conventional steel compound sucker rod and the tubing. The flexible continuous sucker rod mostly depends on hot-extrusion nylon coating to protect the surface. But cracks appear on the surface of nylon coating when the coating has been used in oil well for about one year.

A series of researches on the tribological properties of nylon was made at home and abroad. Most of the experimentations on tribological properties of the nylon are conducted under the condition of dryness or water. But almost nobody conducted tribological properties research on nylon in the oil well environment[2-9]. So it is necessary for us to study the tribological properties of the surface-protecting materials of the flexible continuous sucker rod in the oil well environment.

In this paper, the contrast experiments on the tribological properties of two kinds of nylon coatings used to protect the flexible sucker rod were conducted on a pin-on-disc wear tester in simulated oil field environment.



1. pump 2. weight-adding rod 3. lower linker 4. casing 5. flexible sucker rod 6. tubing 7. above linker 8. steel rod

Fig. 1 Friction force on the flexible sucker rod in oil well

2 Experimental

2.1 Preparation of materials

MO Yi-min(莫易敏): Born in 1960; Prof.; PhD; College of Mechanical &Electrical Engineering, Wuhan University of Technology, Wuhan 430070, China.

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Imported Nylon 6 (Code Name: JKPA), from the Netherlands; Self-made denatured Nylon (Code Name: ZZ7024B): PA6 + POE + bulking agent + hot antioxidant + other auxiliary agents.

Both kinds of compounding formula are determined to protect the flexible continuous sucker rod by Wuhan University of Technology. They have good impact toughness and ductibility at low temperature. So, they are suitable for use under severe working conditions.

2.2 **Test method**

The friction and wear tests were conducted on a self-developed pin-on-disc wear tester. The pin specimens were 45# steel, and both kinds of nylon coatings were made into disc specimens. Fig.2 is the schematic diagram of friction and wear experimentation on a pin-on-disc tester. Both kinds of nylon coatings must be dried for 12 hours at 90℃ in an oven to remove the moisture (because nylon can absorb water at normal temperature). Their sizes were Φ65mm × 10mm. Disc-specimens had lubricous surface without air bubble in them. The emery paper was used to polish the end of the pin-specimen, and then absolute alcohol was used to clean the pin specimen and disc specimen before experimentation.

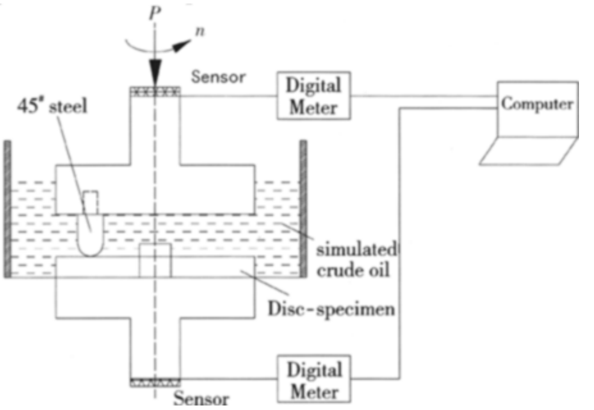

Fig.2 Schematic diagram of friction and wear experimentation on a pin-on-disc tester

The pin-on-disc specimens were dipped in simulated crude oil self-made in accordance with the corrosive medium typical of some oil wells. In the medium, 90vol% is water, 10vol% is 46# hydraulic pressure oil. The actual water content is 80% - 90% in the crude oil from land in China. The content of each kind of ions is listed in Table 1.

Table 1 The Content of Each Kind of Ions in Self-made Simulated Crude Oil (g/L)

K^+, Na^+	Cl^-	Ca^{2+}	Mg^{2+}	SO_4^{2-}	HCO_3^{2-}	ΣFe
40	65	2.5	0.5	0.6	0.2	0.2

The load of each experimentation was: 1kg, 2kg, 3kg, 4kg, 5kg, and 6kg respectively, and the sliding speed was 0.5m/s, 1m/s, 1.5m/s, 2m/s, 2.5m/s respectively. For one test, we used one load with each different speed. Each wear test lasted for 20 minutes.

2.3 **Test equipment**

Injection Molding Machine, from Taiwan; Friction and Wear Tester, Self-made; Scanning Electron Microscope (SEM): JEM - 120EX/9100EDAX, from Japan. Optical analytical scale.

3 Results and Discussion

3.1 The effect of load and speed upon the friction coefficient of ZZ7024B and JKPA

Thirty graphs of the friction coefficient were made by a computer system under the condition of 6 kinds of loads and 5 kinds of sliding speeds. A sample ZZ7024B was made under the condition of being 3kg load and the rotate speed of 730rpm (2.5m/s). The value of the friction coefficient was recorded every 30 seconds by the computer system.

Average values of the two kinds of nylon coatings are calculated and listed in Table 2 and Table 3 according to the thirty graphs above.

Table 2 The Friction Coefficient Values/μ of JKPA with Each Kind of Load and Sliding Velocity at different *V*/(m/s)

L/kg	1.0	2.0	3.0	4.0	5.0	6.0	Σ
0.5	0.1351	0.1598	0.1376	0.1056	0.1261	0.1159	0.1300
1.0	0.1043	0.1333	0.1395	0.1524	0.1482	0.0796	0.1262
1.5	0.0939	0.1174	0.0942	0.0904	0.0958	0.0729	0.0940
2.0	0.0817	0.0546	0.0743	0.0738	0.0617	0.0546	0.0668
2.5	0.0625	0.0441	0.0789	0.0642	0.0647	0.0462	0.0600
Σ	0.0955	0.1018	0.1048	0.0972	0.0992	0.0738	0.0954

Table 3 The Friction Coefficient Values/μ of ZZ7024B with Each Kind of Load and Sliding Velocity at different *V*/(m/s)

L/kg	1.0	2.0	3.0	4.0	5.0	6.0	Σ
0.5	0.1376	0.0839	0.1614	0.1473	0.1030	0.0976	0.1218
1.0	0.1105	0.0899	0.1186	0.1106	0.1006	0.0738	0.1007
1.5	0.0457	0.0490	0.0808	0.0833	0.0654	0.0637	0.0646
2.0	0.0324	0.0494	0.0586	0.0561	0.0571	0.0555	0.0515
2.5	0.0452	0.0447	0.0513	0.0558	0.0495	0.0523	0.0498
Σ	0.0743	0.0634	0.0942	0.0906	0.0751	0.0686	0.0777

Two graphs of the friction coefficient based on Table 2 and Table 3 with load and velocity changing are plotted in Fig.3 and Fig.4.

In Fig.3, when the load is 2kg, the friction coefficient of ZZ7024B decreases abruptly and it is less than that by 0.03 when the load is 3kg. Despite of this abrupt change, the load does not exert a great effect on the friction coefficient. Nor does load exert much effect on the friction coefficient of JKPA. From Fig.4 it can be seen that the friction coefficients of both kinds of materials, JKPA and ZZ7024B used to protect the surface of the flexible continuous sucker rod, decrease with sliding speed increase. The value of the friction coefficient of ZZ7024B is smaller than that of JKPA. The minimum value of the friction coefficient of ZZ7024B is about 0.05.

3.2 The influence of load upon wear volume

Fig.5 shows the wear volumes of ZZ7024B and JKPA as a function of load. The wear volumes of both kinds of materials increase with the load increase. For each load, the wear volume of ZZ7024B is smaller than that of JKPA. With the load increase, the differences of the wear volumes of the two materials become wider. The differences are obvious from 3kg load. So, ZZ7024B performs better than JKPA in terms of wear resistance.

3.3 Wear mechanism

In Fig.6, the SEM (× 500) images of JKPA and ZZ7024B were taken under the conditions of load being

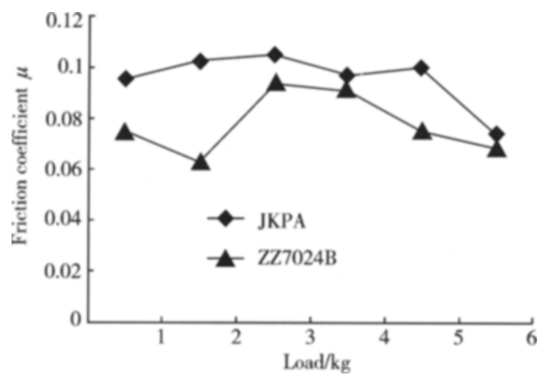

Fig.3 The friction coefficient of ZZ7024B and JKPA as a function of load

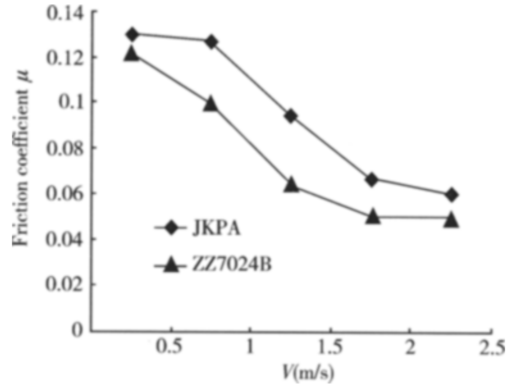

Fig.4 The friction coefficient of ZZ7024B and JKPA as a function of sliding velocity

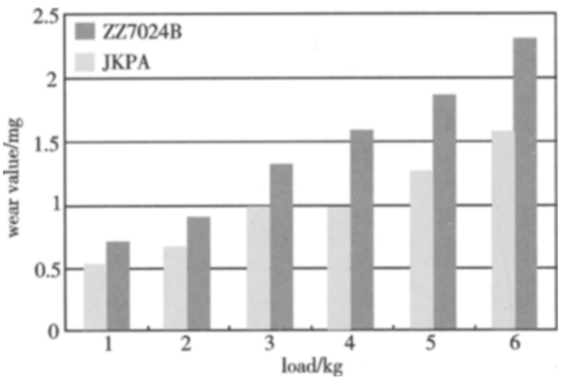

Fig.5 The wear volume of ZZ7024B and JKPA as a function of load

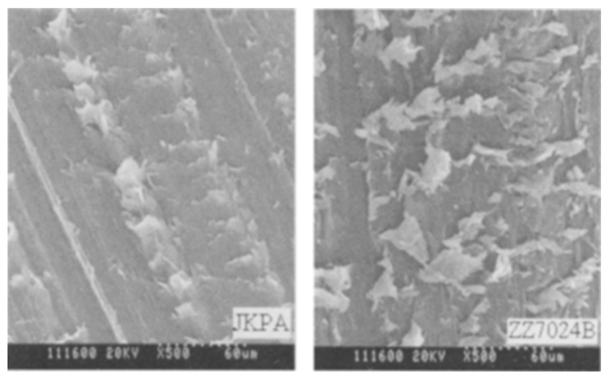

Fig.6 The SEM images under the condition of 3 kg load and rotating speed of 2.5m/s

3kg and rotating speed being 2.5m/s. The wear mechanisms of two kinds of nylon coatings are different. There are some quite obvious furrows and debris on the surface of JKPA. The main causes are adhesive wear and abrasive wear produced by tiny protrusions between pin specimen and disc specimen. In contrast, there are few furrows on the surface of ZZ7024B, but some fatigue delaminations one layer after another. There are some fiber-like substances separating the pin specimen from the disc specimen. The tendency of plasticity distortion and adhesive becomes less. Therefore, the ZZ7024B exhibits a very good wear resistance.

4 Conclusions

a) The capability of wear resistance of ZZ7024B is better than that of JKPA under the condition of the simulated oil well environment.

b) With the sliding velocity increase, the friction coefficients of both surface protecting materials of the flexible continuous sucker rod decrease, but change little with the load increase.

c) The friction coefficient of ZZ7024B is smaller than that of JKPA, the minimum value of the friction coefficient of ZZ7024B is about 0.05.

d) The wear mechanism of the two materials are different. The main mechanism for ZZ7024B is fatigue delamination and abrasive wear, but for JKPA it is adhensive and abrasive wear.

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