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Dope-free Type Premium Connection for Oil Country Tubular Goods

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Abstract

Customarily, compound grease is doped when tightening oil country tubular connections. Eliminating the compound grease attempts to improve environmental and working conditions and a dope-free (grease is not doped) premium joint was developed with the objective of eliminating overall drilling cost. A solid lubricating film was used as a galling resistance processing that can withstand high surface pressures that exist when the screws are tightened. There was no degradation of the lubricating function even in endurance testing that simulated actual use in the field and we were able to ensure usage performance such as shielding equivalent to customary connections. Furthermore, we proved that use in an actual oil well can shorten the casing running time.

1. Introduction

Oil country tubular goods (OCTGs) used for gas and oil drilling are usually coupled by threaded connections. The OCTG connections were traditionally coated with compound greases specified in API 5A2[1] when they were made up. The compound grease contains heavy metal powders, primarily lead powder. Some parts of the world have made an issue of the environmental pollution of heavy metal powders, and some oil companies have switched to the use of compound grease that do not contain heavy metal powders, or what is called green dope[2]. When the compound grease accumulates at its bottom, the well must be frequently cleaned. Depending on the type of well, the contamination of production fluids that contain heavy metals or graphite is very much unwanted. If tubular connections can be used without any fluid lubrication, the above problems would be solved at once, construction performance encumbered by such factors as stabbing difficulty, the hardening of grease in arctic regions and excessively increased joint stress will be improved, and thread inspection and cleaning will be facilitated.

The largest role of the compound grease is to prevent the galling of the seal and the threads during make-up. The authors started research on a surface treatment film with a lubricating function as a substitute for the compound grease. As a result, a new molybdenum disulfide (MoS_2) solid lubricant coating was successfully developed. Premium connections with conventional metal contact portions were coated with the new MoS_2 solid lubricant, and were made and broken 3 times for casing sizes of 194 to 340 mmϕ and 10 times for tubing sizes of 73 to 178 mmϕ without galling and with satisfactory performance properties like seal integrity.

Based on the laboratory work, the new product, designated "dope-free NS-CC (Nippon Steel-type premium casing connection with solid lubricant coating, NS-CC-DF)", was used in actual wells. The dope-free NS-CC connection has demonstrated its ability to solve the environmental problem noted above and to shorten the

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running time of the OCTGs into the wells.

2. Solid Lubricant Coating Suited for Premium Connections for OCTGs

2.1 Description of dope-free premium connection

Fig. 1 schematically illustrates the dope-free NS-CC. The solid lubricant is applied to the coupling joining the casing. The solid lubricant coating is already formed on the coupling at the time of factory shipment. It consists of a phosphate coating as pre-treatment, and MoS_2 as a solid lubricant, bound by polyamide-imide (PAI)[3].

2.2 Galling resistance of surface treatments

Fig. 2 shows a galling evaluation testing machine of the pin-on-disk type used for evaluating the galling resistance of surface treatments. Each surface treatment to be evaluated was applied only to the pin. The disk was rotated at a high contact pressure (Hertz's contact pressure = 2,140 MPa) and at a sliding speed of 5 m/min as encountered by actual connections.

Table 1 lists typical examples of surface treatments used in the screening test. The samples are mainly divided into the soft metal plating type (applied to conventional connections), the dispersion plating type, and the solid lubricant coating type. A dispersion plating has MoS_2 or polytetrafluoroethylene (PTFE) dispersed and mixed in a soft metal matrix. A solid lubricant coating has MoS_2, PAI, or epoxy (EP) sintered on a phosphate coating.

Fig. 3 shows the sliding distance to the galling of each surface treatment in a dry environment. It was found that the resin-bonded solid lubricant coatings markedly improve galling resistance as compared with the conventional surface treatments. In particular, the application of an underlying phosphate coating stabilizes galling resistance at a high level. A dispersion plating with MoS_2, on the other hand, tends to be inferior to the matrix metal in galling resistance.

The above results as evaluated on actual OCTGs are discussed below.

2.3 Galling resistance of actual OCTGs in dry environment

Fig. 4 shows the number of make-and-break times to the galling of NS-CC connections with an outside diameter of 178 mm in a dry environment. The actual OCTG test results generally agree with the rankings shown in **Fig. 3**. The conventional methods of use (soft metal plating or phosphate coating combined with compound grease) did not result in galling within 10 make-and-break times, but resulted in galling within 3 make-and-break times when the compound grease was not applied. Galling was conspicuous in the seals, to which high contact pressure was imparted, to assure leak resistance.

The solid lubricant coating shown in **Fig. 1** did not cause galling after 10 make-and-break times as recommended by the American Petroleum Institute (API). Thinking that the solid lubricant coating

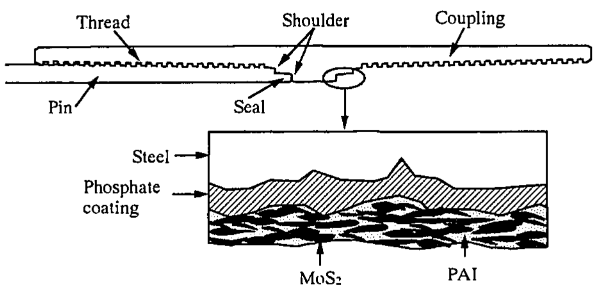

Fig. 1 Schematic illustration of NS-CC and solid lubricant coating

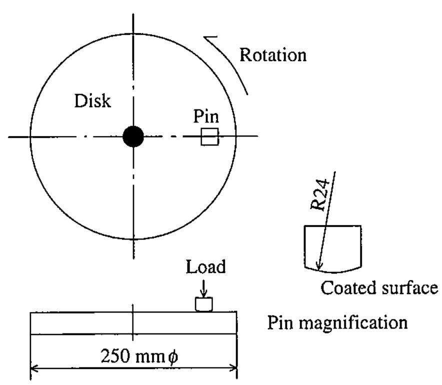

Fig. 2 Galling evaluation testing machine

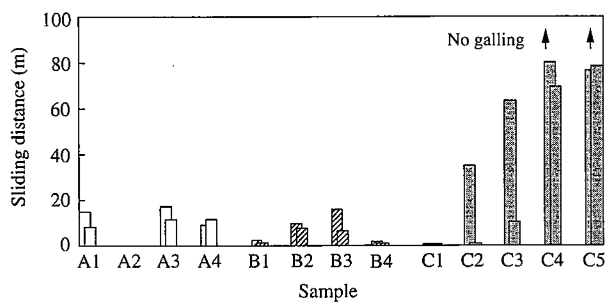

Fig. 3 Galling resistance of surface treatments

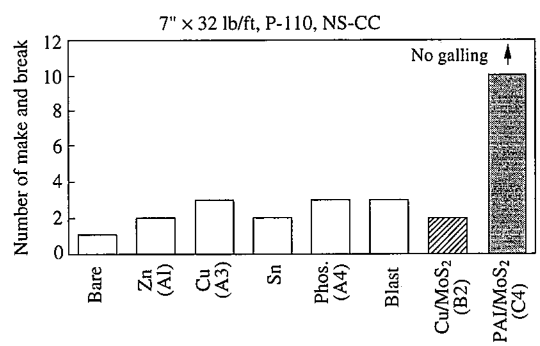

Fig. 4 Galling resistance of connections in dry environment

Table 1 Surface treatments used in screening test

Group	Metal plating				Dispersion plating				Solid lubricant coating				
Sample No.	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4	C5
Pre-treatment			Ni							Blast	Nitride	Phos.	Phos.
Matrix	Zn	Ni	Cu	Phos.	Cu	Cu	Cu	Zn	PAI	PAI	PAI	PAI	EP
Solid lubricant					SiC	MoS_2	PTFE	PTFE	MoS_2	MoS_2	MoS_2	MoS_2	MoS_2

Table 2 Combinations of connection test conditions simulating field environment

Simulation condition	Test items	Environmental medium					Temperature (°C)				Pressure (MPa)	
		Gas	Water	Grease	Oil	H_2S	R.T.	– 40	– 20	170	0.1	97
Standard	M&B*	×					×	×			×	
Storage	Wetting		×				×				×	
	Thermal cycling				×					×	×	
	Low temp.	×						×			×	
	Coating damage	×					×				×	
Running	Grease M&B	×		×			×			×	×	×
	Low temp.	×							×		×	
	Field repair	×					×				×	
Working	Sealing proof	×								×		×
	SSC					×	×				×	

*M&B : Make and break

composed of the lower phosphate coating and the upper layer of MoS_2 sintered in PAI is ideal, the authors decided to use it in OCTG tests under simulated field conditions.

2.4 Galling resistance under simulated filed conditions

Unlike the laboratory, the actual working environment presents severe storage and running conditions. The combinations of simulated field environmental conditions are given in **Table 2**. No fatal degradation of galling resistance was observed under any environmental conditions.

(1) Storage environment

Wet environment: Galling resistance when the coupling is immersed in industrial water without rust inhibitor for 10 days and the connection is then made and broken in a water spray environment.

Temperature: Galling resistance after application of 100 cycles or more of thermal shock of 67 to 163°C for more than 1 week, and galling resistance after storage at – 40°C.

Mechanical coating damage: Galling resistance when a defect is caused in the solid lubricant coating (refer to **Fig. 5**). Galling resistance after mechanical shock with a hammer at – 40°C and after peel test with a screwdriver.

(2) Running environment

Use of compound grease: Galling resistance when the compound grease is used as before. Galling resistance when the connection is made up alternately with and without the compound grease.

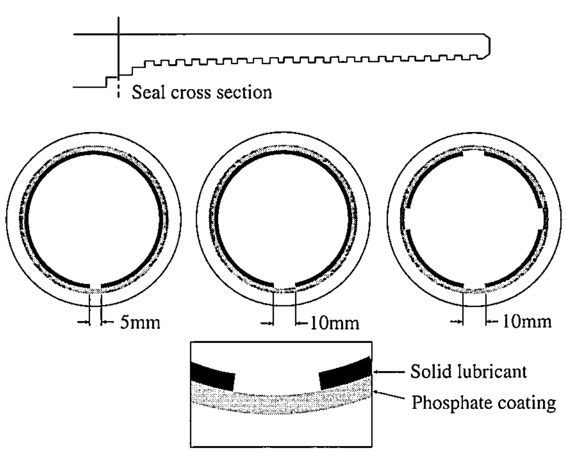

Fig. 5 Artificial defects in solid lubricant coatings

Low-temperature make-up: Galling resistance when the connection is stored at – 40°C and is made and broken at – 20°C.

Vertical make-up: The weight of pipe works on the connection being made up using the vertical type power tong.

Mix make-up: Galling resistance when the coupling and pin are not in the same pair or interchanged, and after the pin is repaired.

(3) Working environment

After high-pressure operation: Galling resistance after the connection is sealed with high-pressure gas.

After exposure to hydrogen sulfide: Galling resistance after the connection is exposed to hydrogen sulfide (solution equivalent to that specified in NACE TM0177-90A).

The results of the above-mentioned tests indicate that the solid lubricant coating can stably maintain its lubricating function in the field environment.

3. Actual Service Performance

(1) Gas sealing performance

The dope-free NS-CC connection is confirmed to maintain the desired sealing performance by an evaluation program based on API RP 5C5[4].

Oil companies place great expectations on the gas sealing performance of the dope-free NS-CC connections at high temperatures under which the compound grease is not expected to contribute to the sealing performance. The simulated test shown in **Fig. 6** was carried out. **Fig. 6** shows a testing apparatus to simulate a steam injection well, which is a typical high-temperature well. The connection is placed in the electric oven and heated to 260-354°C.

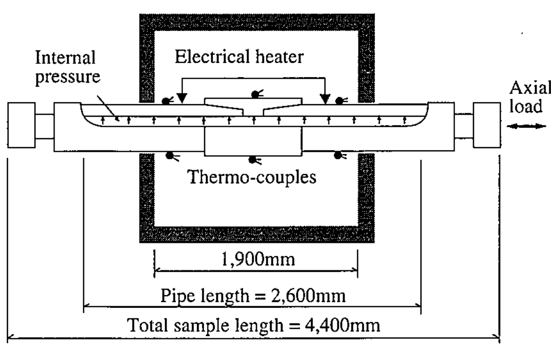

Fig. 6 Thermal well simulator

The axial thermal expansion is restrained to simulate the load to which the connection would be subjected in a steam injection well. At the same time, the internal gas pressure is applied to the connection to evaluate its seal integrity as well.

Fig. 7 shows the load-temperature hysteresis curves obtained in the steam injection well simulation test. The restraint of thermal expansion produced a compressive load 1.5 times as large as the pipe body yield strength when the connection was heated to 354°C, but the connection did not leak.

In this way, the dope-free NS-CC premium connections were found to have excellent gas sealing performance in not only ordinary wells but also high-temperature wells exceeding 300°C.

(2) Collapse resistance

Table 3 lists the external pressure test results of the dope-free NS-CC premium connections. The pipe body was NT-110HS for the high-collapse specification. Samples C1-A, C1-B, and C2-A were not coated with compound grease, and made and broken 10 times. Sample C2-B was coated with compound grease as control material, and was made and broken 10 times. Each sample was then external pressure tested. Application of an external pressure at least 1.4 times as large as the guaranteed collapse strength of API P-110 did not cause the connection to leak. A collapse finally occurred in the pipe body.

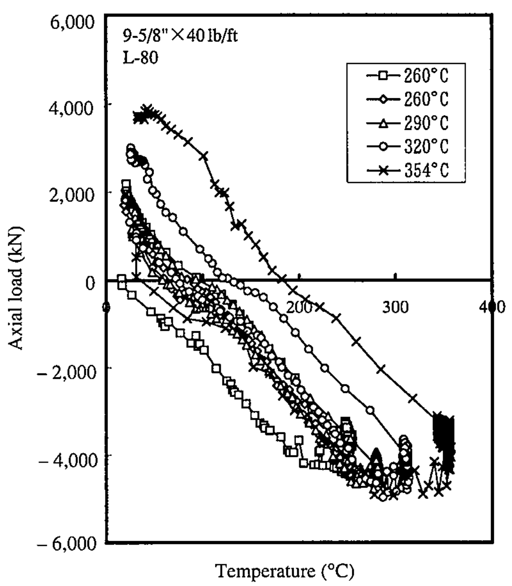

Fig. 7 Load-temperature hysteresis curves

Table 3 External pressure test results

Size : 7" × 29 lb/ft, Grade : NT-110HS

Sample No.	Side*	Grease	Galling resistance	External pressure seal	Collapse resistance Pressure (MPa)	Mode
C1	A	No	No galling (10-M&B)	No leaking	87.0	Pipe collapse
	B	No	No galling (10-M&B)	No leaking		
C2	A	No	No galling (10-M&B)	No leaking	86.5	Pipe collapse
	B	Yes	No galling (10-M&B)	No leaking		

*Side A : Mill end, Side B : Field end

Table 4 Tensile failure test results of connections

Sample No.	Side	Interference seal/thread	Thread taper pin/CPLG	Failure test results Fracture mode	Load W (kN)	Ratio W/Ws*
T1	A	min/min	nom./nom.	Pipe fracture	5,900	1.18
	B	max/max				
T2	A	min/min		Jump-out	6,380	1.28
	B	max/max				
T3	A	min/min	slow/fast	Jump-out	5,710	1.15
	B	max/max				
T4	A	min/min		Pin fracture	5,920	1.19
	B	max/max				
T5	A	min/min	fast/slow	Jump-out	6,420	1.29
	B	max/max				
T6	A	min/min		Pipe fracture	6,050	1.21
	B	max/max				

*Ws : Specified joint strength of API BTC (4,980 kN)

(3) Tensile strength

The tensile failure test results of the dope-free NS-CC are given in **Table 4**. When the tensile strength of the dope-free NS-CC was evaluated by the combinations of thread interference and thread taper within manufacturing tolerances, the dope-free NS-CC connections with the combination of small thread interference, slow pin taper, and fast coupling taper exhibited the lowest tensile strength, but exceeded the specified strength of the API buttress-thread joint. The dope-free NS-CC connections were thus found to guarantee tensile strength equivalent to that of conventional connections.

(4) SSC resistance

The possibility of sulfide stress corrosion cracking (SSC) was experimentally studied concerning the evolution of hydrogen sulfide (H_2S) from MoS_2. As a result, it was confirmed that H_2S evolved from MoS_2, but in extremely small amounts and not continuously with time as to induce SSC[3]. The joint stress, another environmental factor, was also found to be far smaller as compared with grease make-up.

As described above, the dope-free NS-CC demonstrated service performance equivalent to that of conventional premium connections, without using compound grease.

4. Field Runability

The field runability of the dope-free NS-CC is described by taking the example of horizontal steam-aided gravity drains (SAGD) in an oil sand development project in Canada. **Fig. 8** shows the SAGD casing design. Forty-five dope-free NS-CC joints were used in 9-5/8" × 40 lb./ft., L-80 surface casing. All joints were made-up under adequate torque control and successfully run[5]. Make-up is controlled mainly according to the tightening torque. The make-up torque of the dope-free NS-CC is set higher than that of the conventional NS-CC connections and API connections, in order to absorb the torque variations (refer to **Fig. 9**).

Fig. 10 compares the casing running time of NS-CC coated with compound grease and run into wells of the same type. The running time of the dope-free NS-CC connection run at the third time is clearly shortened. This may be ascribed to the combined effect of grease application, ease of stabbing, and ease of axial alignment.

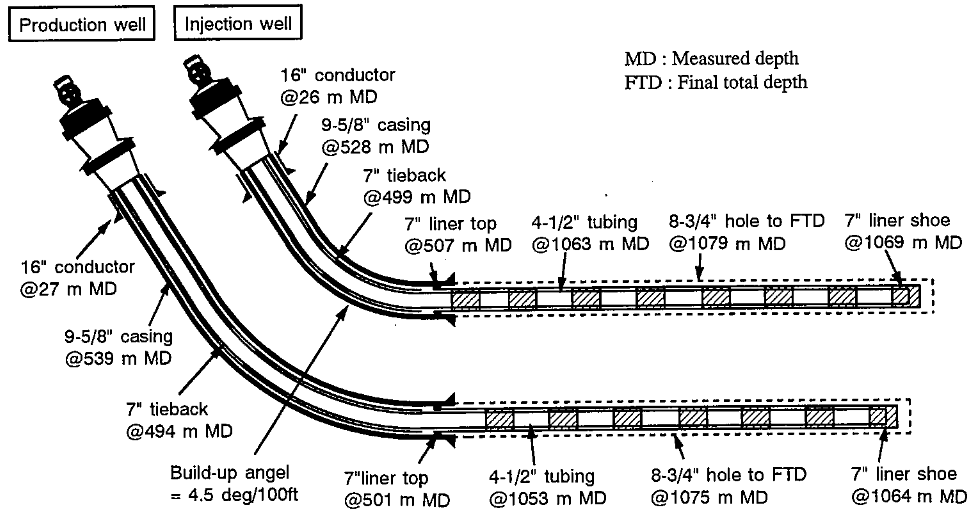

Fig. 8 SAGD casing design

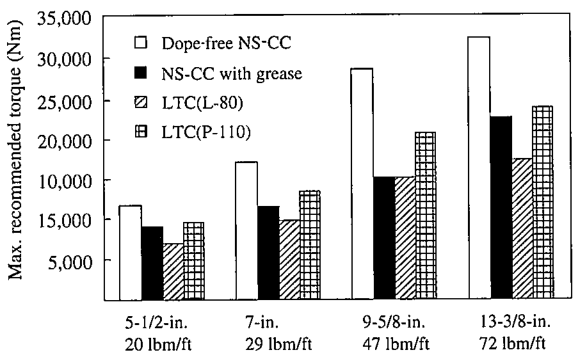

Fig. 9 Recommended make-up torque values

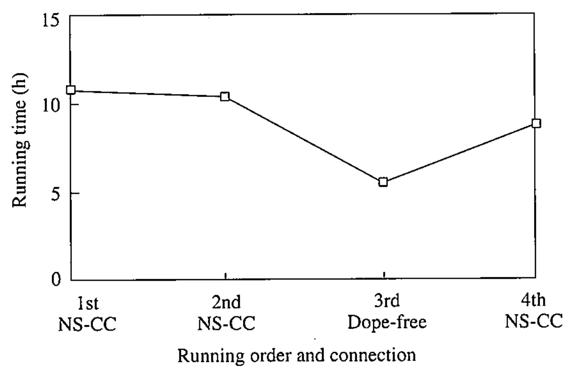

Fig. 10 Comparison of casing running time

5. Conclusions

Dope-free NS-CC have been successfully developed as new OCTG connections capable of being made up without any liquid lubricants and providing service performance equivalent to that of conventional connections. This technology is expected to find increasing usage in many fields with stiffening environmental regulation and diminishing total drilling cost.

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