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How do Oil Country Tubular Goods Lubricants work? – An Autopsy of Thread Compounds

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Abstract

Thread compounds are commonly used in the oil industry in order to facilitate the makeup process of a wide variety of Oil Country Tubular Goods (OCTG). Whether tubing, casing or Rotary Shouldered Connection the compound must offer consistent frictional properties, adequate lubrication and sealing properties, physical and chemical stability both in service and in storage conditions, as well as properties that allow the efficient application of the compound on the connection surfaces. This paper presents experimental results that show some inconsistencies with the API assumptions regarding the thread compound behaviour at high contact pressures (as for RSC applications). The performance of the thread compound during the makeup process will be also explained.

Keywords: *OCTG, Thread, Compound*

Introduction

The new connection designs introduced by the drill pipe manufacturers (double shoulder connections, intelligent drill pipes or any new design for increased torque resistance) make the use of the Farr formula for calculating proper assembly torque more problematic, since the equation has been developed for external shoulder connections, specifically for API Rotary Shouldered Connections (RSC) [9]. Additionally, severe drilling conditions like High-Pressure High-Temperature (HPHT), directional drilling and extreme environments are affecting the thread compound performance properties, which can make it impossible to attain the optimum makeup torque for the connection. Oil Country Tubular Goods (OCTG) rely on tapered threads to connect them. An adequate connection between two drill pipes depends on the quality of the assembly process, which is significantly affected by the thread compound performance. Since the variety of the thread compounds is great, standards have been developed to determine the thread compound performance and to define the minimum thread compound properties.

Thread Compounds for Oil Country Tubular Goods (OCTG)

The typical thread compounds for very OCTG are formed using base grease in which solid particles are dispersed. The grease is standard lubricating grease, made of mineral oil and having a metal soap as thickener (i.e. aluminum stearate). Additives are added in low amount to the compound to improve the following properties: high pressure resistance, wear protection, corrosion protection, etc.

The role of the solid particles is to provide anti-galling resistance and sealing properties of the compound. Powdered metals and non-metallic particles like graphite or ceramic spheres are used as solid ingredients. Typical metals used for thread compounds manufacturing are: lead, copper, zinc. The common non-metallic solids used for compounds are graphite, PTFE, ceramics.

The so called “green dope” or environmental friendly compounds have a totally metal-free composition. **Figure 1** shows a classification scheme of the thread compounds after [10]. **Table 1** shows the composition of some common thread compounds used in the oil industry, including the tested thread compounds described in this paper.

According to [4] the performance general requirements of the thread compounds include: consistent frictional properties, adequate lubrication and sealing properties, physical and chemical stability both in service and in storage conditions, and properties that allow the efficient application of the compound on the connection surfaces. In addition, the thread compounds for Rotary Shouldered Connection should lubricate the connection during the make-up runs to achieve bearing stresses (buck-up force). The sealing capacity or, according to some authors, leak tightness, is provided by the high viscosity of the thread compound and the small free path inside of the threaded connection. Every commercially available thread compound has its own characteristics that are measured and reported. Figure 2 shows such report as given in the product specifications. It must be noted that the thread compound viscosity is not reported for OCTG compounds.

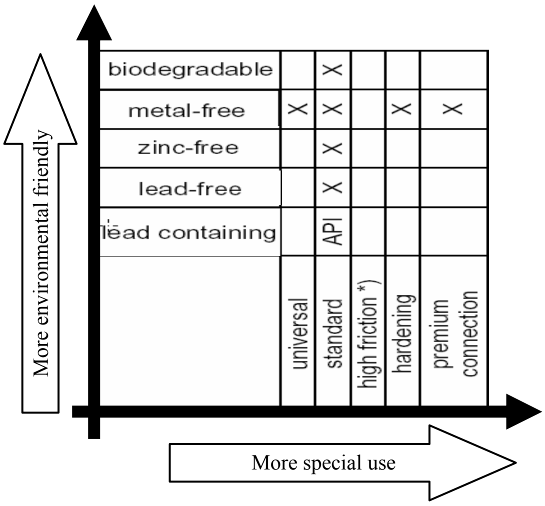

Fig.1. Classification Scheme of Thread Compounds, after [10]

Table 1. Various thread compounds composition

Product Specification	**API Mod. Compound**	**Copper-Based Compound**	**50% Zn**
Grease Base	36.0%	60%	50%
Powdered Graphite	18.0%	10-15%	-
Lead Powder	30.5%	-	-
Zinc Dust	12.2%	-	50%
Copper Flake	3.3%	10-15%	
Fluid Type	Petroleum	Petroleum	Petroleum
Density	1900 kg/m³	1200 kg/m³	1750 kg/m³
Color	Black/Brown	Brown	Gray

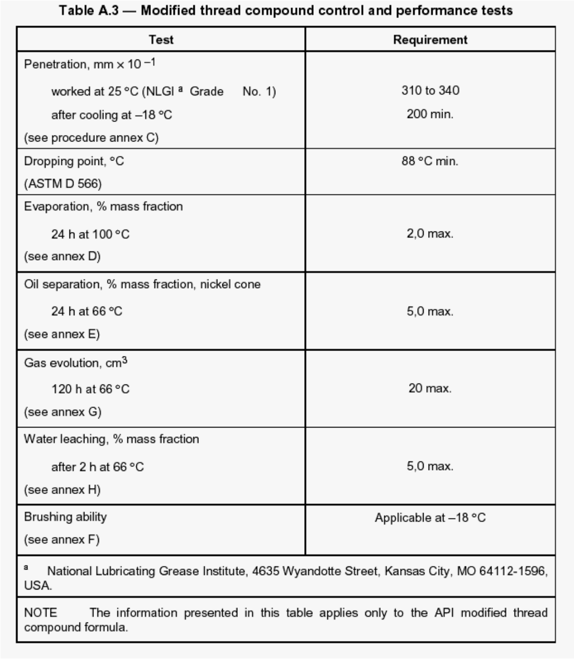

Table A.3 — Modified thread compound control and performance tests

Test	Requirement
Penetration, mm × 10^{-1} worked at 25 °C (NLGI [a] Grade No. 1) after cooling at –18 °C (see procedure annex C)	 310 to 340 200 min.
Dropping point, °C (ASTM D 566)	88 °C min.
Evaporation, % mass fraction 24 h at 100 °C (see annex D)	2,0 max.
Oil separation, % mass fraction, nickel cone 24 h at 66 °C (see annex E)	5,0 max.
Gas evolution, cm^3 120 h at 66 °C (see annex G)	20 max.
Water leaching, % mass fraction after 2 h at 66 °C (see annex H)	5,0 max.
Brushing ability (see annex F)	Applicable at –18 °C

[a] National Lubricating Grease Institute, 4635 Wyandotte Street, Kansas City, MO 64112-1596, USA.

NOTE The information presented in this table applies only to the API modified thread compound formula.

Fig. 2. API modified thread compound characteristics as reported in product specifications, after [15]

Friction Process

Friction is characterized by a coefficient of friction (COF), which is defined as the ratio of the frictional resistance force to the normal force between contacting surfaces [8]. A significant difference exists between the coefficients of static friction and kinetic friction. The static friction coefficient does not characterize the static friction in general, but represents the condition at the threshold of motion only [8]. The static frictional forces developed by the interlocking of irregularities of two surfaces will increase to prevent any relative motion, up to the limit condition where motion occurs. It is that threshold of motion, which is characterized by the coefficient of static friction. The coefficient of static friction is larger than the coefficient of kinetic friction. When coefficients of friction are quoted for specific surface combinations, they are generally referenced to the kinetic coefficient. Thus, the static coefficient of friction exists as long as no relative motion occurs between the two bodies. This situation appears when OCTG thread “make-up” or “break-out” is imminent [14]. Three basic assumptions are generally considered to characterize a model for friction between contact surfaces [7]:

1. The frictional force is independent of the contact area;
2. The frictional force is proportional to the normal force;
3. The frictional force is independent of the velocity of motion.

These assumptions are valid for a wide range of applications. For some complex applications, as in bearings and threaded connections, these assumptions are not adequate to define all cases. For example, in case of pressure lubricated bearings the hydrodynamic lubrication prevents the contact between bearing elements and therefore, the friction coefficient becomes more a function of the lubrication fluid shear stresses. A second example will be presented in this paper that refers to the extreme contact pressure situation in which the friction coefficient becomes a function of the thread compound composition and the contact pressure.

In the early days of drilling, very little attention has been paid to the friction coefficient. Usually, it was considered being equal to 0.2 [9]. Later investigations showed that the friction coefficient without dope has a value of 0.133, while the common dope used at that time (60%

lead powder and 40% grease base) showed a friction coefficient equal to 0.08 [9]. The experimental tests conducted by Farr showed that the 0.08 value is a practical choice, since it was matching the relationship between makeup torque, buck-up force and the geometry of the connection.

API SPEC 7 [6] as well as ISO 10407 [7] recommend two main compound types for RSC: 40% to 60% zinc-based for tool joints and 40% to 60% zinc-based or 60% lead-based for drill collars. The API Reference Compound, a lead-based compound, is used only for laboratory testing. The accepted friction coefficient for the API Reference Compound is 0.08. The API Modified Compound, a multi-component compound containing 30 wt.% lead (Table 1), provides a similar friction coefficient as the API Reference Compound ($\mu = 0.08$) at typical tool joint (NC-46) contact stress. Because the loads on RSCs are increasing substantially, the demand for reliable and predictable thread compound properties is also increasing. Several types of drilling compounds have been developed and tested under extreme conditions. Compounds, such as copper-based or green (metal free) compounds are being used today for RSCs. Because the composition of many compounds is proprietary and can be changed by the producer, new methods were created to compare and measure their friction coefficient. The results of such methods are a general (global) friction coefficient or, according to API, a correction factor FF [2]. This correction factor represents the ratio between the API friction coefficient ($\mu_{API} = 0.08$) and another friction coefficient:

$$FF = \frac{\mu_{test}}{\mu_{ref}} = \frac{\mu_{test}}{\mu_{API}} = \frac{\mu_{test}}{0.08}.$$

The friction coefficient for compounds may vary as a function of the contact force. For dry friction (non-lubricated surfaces or metal-to-metal friction) the friction coefficient is a constant value. By interlaying a single-phase lubrication material between the contact surfaces, the friction coefficient becomes a function of the relative speed between surfaces. When a multi-phase lubrication material such as a thread compound is used, the friction coefficient is a complex function of different factors that include not only the compound composition but also the connection geometry, material and contact surface finish. It should be noted that what this paper defines is an “apparent” COF of the complete compound/connection “system”.

Experimental Data Related to Friction Coefficient

In the past 15 years several investigations have been dealing with friction phenomena in threaded connections. Sawitzky [13] stated in his thesis that the friction coefficient at the shoulder differs from the friction coefficient in the thread. His tests were performed on an apparatus based on a previous API 7A1 test machine. Because of the low contact pressure, the results were not conclusive for shouldered threaded connections, where high contact pressure exists. Investigations on thread compound friction coefficient have been paralleled by an expansion in the variety of thread compound compositions. Same values have been reported by Sawitzky for low contact pressures. Although Sawitzky did not extend his investigations at higher contact pressure, all his data points showed a decrease of the friction coefficient once the contact pressure exceeds 1.4 MPa.

Earlier tests [11] showed a discrepancy between full scale tests (Tool Joint) and small scale setup (Nut and Bolt machine) in which friction coefficients measured on the nut and bolt machine showed lower values than for the full scale tests. Although this aspect has not been explained at that time, the only logical answer is that the thread flank load distribution in the samples may affect the results.

The contact pressure for RSCs at the shoulder, however, reaches values up to 800 MPa. The friction coefficients of various compounds were tested at high contact pressures (300-500 MPa) in an API sponsored project [3] and are presented in the Figures 3 to 5.

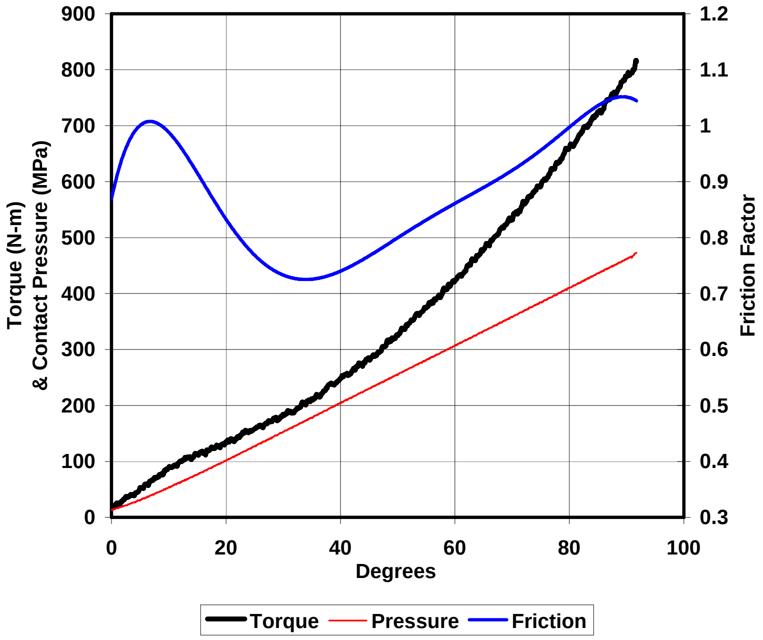

Fig.3. Torque-turn results with single component lubricant (Single component fluid lubricant with small percentage of PTFE. Note the different shape of the friction curve compared to all multi component compounds) [3]

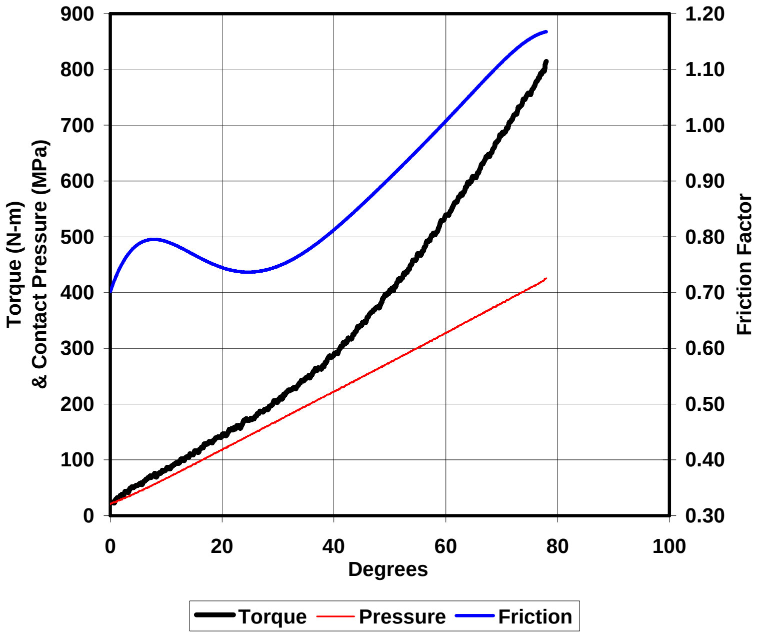

Fig.4. Torque-turn results with copper based compound [3]

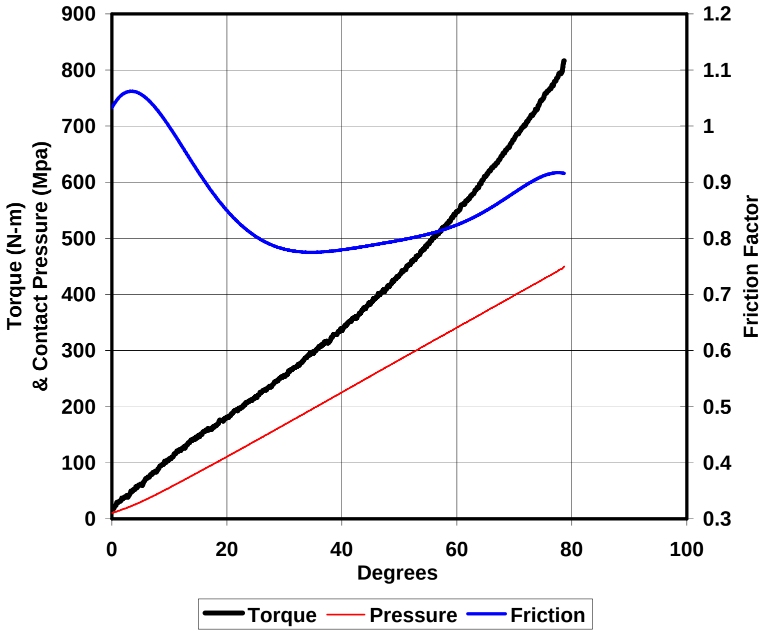

Fig.5. Torque-turn results with zinc based compound [3]

The Influence of Compound Composition during Make-Up

A simple scheme will be used to describe the compound behaviour during makeup conditions. Consider two plates with a given volume of compound between them, as presented in Figure 7. The normal force N on both plates will create a friction force F_f when the plates start moving relative to each other. If the pressing force N is low, then the lubricant phase within the compound creates the friction, while the metallic particles are able to move in parallel layers without creating a noticeable resistance. By increasing the force N, the solid particle layers come closer to each other and their resistance will increase up to a greater, measurable value. When the force N becomes even higher, the metallic particles are plastically deformed and the friction force becomes a function of the normal force N and the tribological properties of the metallic particles. When the particles are deformed into the shape of flakes (small plates), localized friction occurs between these layers. This global, friction coefficient is in transition to some function of metal-on-metal friction.

If the solid particles are not ductile or deformable, the change in the COF may become even more dramatic. An example would be ceramic particles in spherical form or amorphous graphite. In the case of the ceramic spheres, the measured friction can be quite low initially, as the particles roll between the contact surfaces like bearings, and then become extremely high, as the contact pressure increases and the particles fracture and become abrasive.

Conclusions

The thread compounds used for OCTG threaded connections play an important role to seal and lubricate them.

It has been shown that at a higher contact pressure the frictional properties of the OCTG threaded connections vary. This is in contradiction with the API assumption of a constant friction coefficient with a value of 0.08.

The composition of the thread compound is the key in understanding its behavior under high contact pressures.

The paper has presented a simple model that can explain the compound behavior at high contact pressure, although more experimental work will be necessary to fully understand this behavior.

As presented in the paper, the frictional properties of the thread compounds, especially when exposed to high contact pressure, depend on the mechanical properties of the solid particles included in the base grease. Future developments of such compounds must consider these aspects.

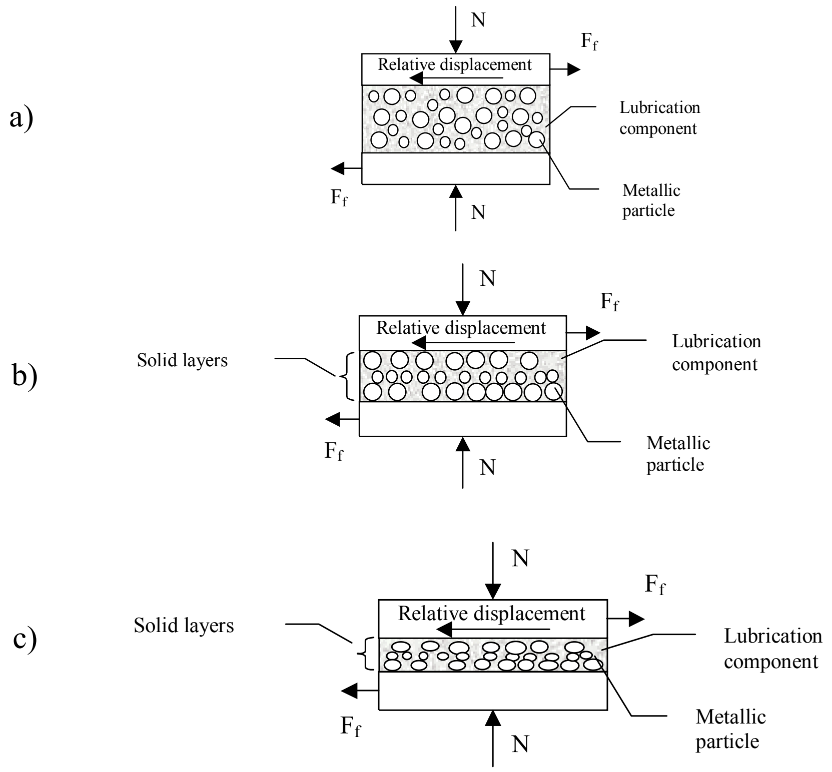

Fig.7. Compound behaviour as a function of normal force

References

1. ***, API RECOMMENDED PRACTICE 7G (RP 7G), Recommended practice for drill stem design and operating limits, 1998.
2. ***, API RECOMMENDED PRACTICE 7A1 (RP 7A1), Recommended practice for testing of thread compound for rotary connections, first edition, 1992.
3. ***, Test data from API E&P SC5 Work Item 1033 - “Thread Compound Research”.
4. ***, Ansys User Manual, 2006.
5. ***, ISO13678:2000(E), Petroleum and natural gas industries - Evaluation and testing of thread compounds for use with casing, tubing and line pipe.
6. ***, API SPECIFICATION 7 (SPEC 7), Specification for rotary drill stem elements, 1999.
7. ***, ISO 10407, Petroleum and natural gas industries - Drilling and production equipment - Drill stem design and operating limits, 2000.

8. ***, Dubbel - Taschenbuch fuer den Maschinenbau, Springer Verlag, Berlin, 1999.

9. Baryshnikov, A., Ferrara, P., Schenato, A., and Curioni E., *Makeup Torque and Rotary Shouldered Connection Reliability*, SPE/IADC 29352, SPE/IADC Drilling Conference held in Amsterdam, 28 February - 2 March, 1995.

10. Holcomb, R.T., Wilcox, V.T and Oldiges, D.A., *The Performance Characteristics and Economics of Rotary Shouldered Connection Thread Compounds*, IADC/SPE 14794, IADC/SPE Drilling Conference held in Dallas, TX, February 10-12, 1986.

11. Hoenig, S., Oberndorfer, M., *Tightness Testing of Environmentally Friendly Thread Compounds*, SPE 100220, SPE Europe/EAGE Conference, Vienna, Austria, 12-15 June, 2006.

12. Holcomb, R.T., Wilcox, V.T and Oldiges, D.A., *The Performance Characteristics and Economics of Rotary Shouldered Connection Thread Compounds*, IADC/SPE 14794, IADC/SPE Drilling Conference held in Dallas, TX, February 10-12, 1986.

13. Farr, A.P., 1976, *Tool Joint Design and Operation Torque*, IADC Rotary Drilling Conference, Dallas, 1976.

14. Sawitzki, *Untersuchungen der Reibungsverhältnisse beim Verschraubvorgang und Analyse der daraus resultierenden Beanspruchungen hochbelasteter Gewindeverbinder*, Doktorarbeit, 1987.

15. Teodoriu, C., *Analysis of the Makeup procedure and evaluation of conical shouldered threaded connections*, Ph.D. Thesis, TU Clausthal, 2003.

16. Badicioiu, M., Teodoriu, C., *Sealing Capacity of API Connections - Theoretical and Experimental Results*, SPE 106849, SPE Drilling and Completion Journal, 2008.

Cum functioneaza unsorile pentru material tubular petrolier? O autopsie a unsorilor pentru filete

Rezumat

Unsorile pentru filete sunt folosite in industria petroliera in scopul imbunatatirii si optimizarii procesului de insurubare a materialului tubular petrolier, cunoscut sub numele de OCTG. Indiferent de tipul filetului, pentru burlane, tevi de extractie sau racorduri speciale, unsorile trebuie sa aiba proprietati tribologice reproductibile si constante, proprietati de ungere adecvate scopului lor, proprietati care sa asigure o etansare optima a filetului, proprietati fizice si chimice compatibile cu aplicatia si, nu in ultimul rind, proprietati care sa permita o aplicare uniforma a unsorii pe filet. Aceasta lucrare prezinta rezultate experimentale care sa sustina faptul ca unsorile pentru filetele racordurilor speciale au o comportare diferita de definitia data de API, conform careia coeficientul de frecare are o valoare fixa de 0.08. De asemenea, se va incerca explicarea proceselor care au loc in interiorul unsorii in timpul procesului de insurubare, fapt care poate ajuta constructorii de unsori la dezvoltarea unor unsori cu proprietati imbunatatite.