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Determining Robust Friction Coefficient for Bolted Closure System

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Abstract

Dual purpose transport/storage casks for radioactive materials use either a welded or bolted closure system: the latter being easier for the retrieval of the content.

For the bolted design, the preload of closure bolts is a key parameter in ensuring a high level of containment integrity. The most practical method to control the preload is based on setting the tightening torque. The specified torque is usually obtained with a calibrated torque wrench. Torque wrenches are easy to calibrate in the controlled areas of the loading and unloading facilities.

The value of the global friction coefficient is needed to define the torque required for the adequate preload in the closure bolts. The dispersion of the friction coefficient value has a direct impact on the dispersion of the preload to be considered in the safety analysis.

The friction coefficient value can be affected by several variables: the type and the nature of the lubricant, the bolts, nut and washer materials, the engaged length, the torque level… Even for a given configuration (same lubricant and materials), there is a natural dispersion of the friction coefficient.

This paper describes how the dispersion of the friction coefficient can be evaluated by tests. Several sets of bolts (screws)/washers/threaded base material are needed to evaluate the dispersion for each fastening configuration. After each tightening/untightening, the assembly is degreased and regreased. The first 5 tightenings are the most significant. Depending on the torque level, during the 5 first tightenings there is a wearing effect of the surface in contact (bearing area and threads) and an associated decrease in the friction coefficient.

Robust closure system design can be achieved by reducing the uncertainty on the preload by qualification tests of the friction coefficient.

Introduction

Most dual purpose transport/storage casks for radioactive materials use a bolted closure system. This solution for the cask closure offers a robust solution for the retrieval of the content. It is routinely used for transport casks such as those in the TN fleet in France used for shipping used fuel to reprocessing. For such a design, the preload of closure bolts is a key safety parameter. Integrity of the containment is directly linked to the preload of the closure bolts considered in the safety analysis.

The most practical method to control the preload is based on the setting of the tightening torque. Torque-controlled tightening is the most widespread method due to its cost-effective tools and easy handling. This method uses tools that measure the torque transferred to the fastener and then either gives a signal or turns off when the desired torque is reached. The torque wrenches are wide spread and robust tools. They are easy to use in the controlled areas of the loading and unloading facilities. Affordable on-site calibration is possible.

A limited part of the applied torque is transferred to the fastener. A significant part of the torque applied is lost due to the friction in the bearing area and the threads (Figure 1).

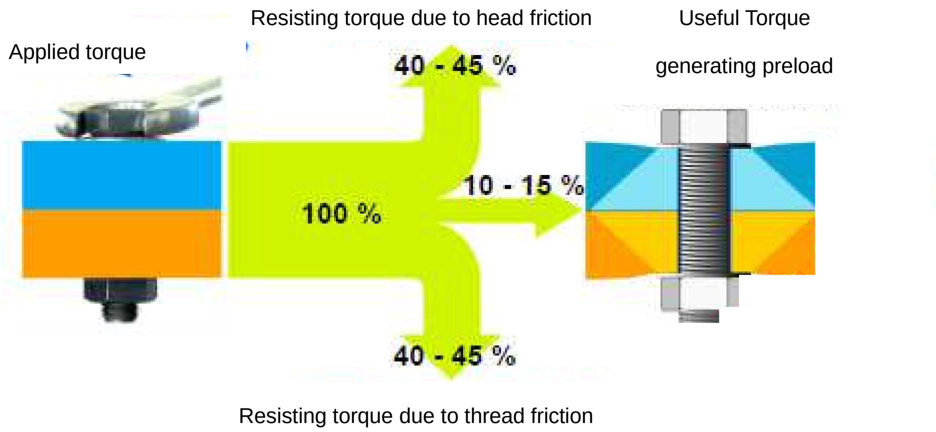

Figure 1 Tightening torque used for the preload

To define the tightening torque necessary for the adequate preload in the closure bolts the value of the global friction coefficient is needed. The dispersion of the friction coefficient value has a direct impact on the dispersion of the preload.

The minimum and maximum preload is a function of the following parameter:

- $F_{0min}=F_0(C_{min}, \mu_{max})$
- $F_{0max}=F_0(C_{max}, \mu_{min})$

with :

F_{0min} = minimum preload generated by the tightening torque applied on the bolt

F_{0max} = maximum preload generated by the tightening torque applied on the bolt

C_{min} = Mimimum tightening torque : C_{min}= C_{nom} .(1-ΔC)

C_{max} = Maximum tightening torque : C_{max}= C_{nom} .(1+ΔC)

C_{nom} = setting of the torque wrench

ΔC = accuracy of the torque wrench

μ_{min} = minimum friction coefficient

μ_{max} = maximum friction coefficient

The friction coefficient value can be affected by several variables: the type of lubricant, the bolts, nut and washer materials, the engaged thread length, the torque level… Even for a given configuration (same lubricant and materials) there is a natural dispersion of the friction coefficient.

The variation of the friction coefficient was evaluated by tests in accordance with ISO 16047. Several sets of bolts (screws)/washers/threaded base material are needed to evalute the dispersion of the friction coefficient.

Testing Equipement

The type of test bench (Figure 2) used for the measurement applies a tightening torque to the bolt head automatically. It was fitted with a calibrated measuring device of the angle, the torque, and the load with an accuracy of +/-2% of the measured parameters (Figure 3). The accuracy on the angle was also +/- 2° or +/-2 % if the angle is greater than 360°. The measuring device met the ISO 16047 requirements. The number of turns per minutes was set to 5 turns/min. The parameters were recorded throughout the test duration.

Figure 2 Test Bench

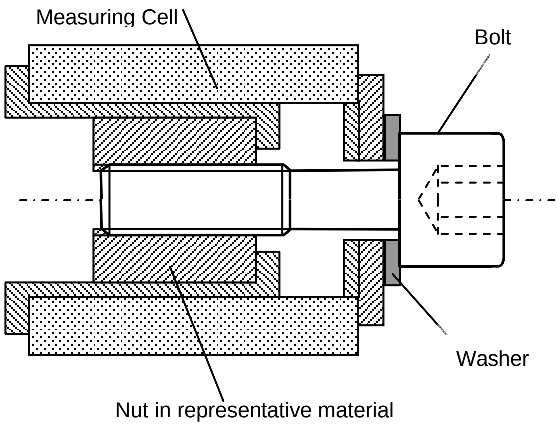

Figure 3 Test Principles

Tests

The global friction coefficient μ_{tot} was computed according to the formula given in the ISO 16047 standard.

$$\mu_{tot} = \frac{\frac{T}{F} - \frac{P}{2\pi}}{0{,}577 d_2 + 0{,}5 D_b} \qquad D_b = \frac{D_o + d_h}{2}$$

d_2	Basic pitch diameter of thread
D_o	External diameter of washer or bearing part (nominal value)
d_h	Clearance hole diameter of washer or bearing part (nominal value)
D_b	Diameter of bearing surface under nut or bolt head for friction (theoretical or measured)
F	Clamp force
P	Pitch of the thread
T	Tightening torque

A large number of bolts were tested to properly evaluate the dispersion of the friction coefficient. Each bolt was submitted to tightening and untightening cycles. After each untightening the body was cleaned and again greased before starting a new cycle. The grease used was the same as the one used during cask operations. The tests were done at room temperature. The bearing area and the threads were greased (Figure 4).

After 5 cycles (end of the wearing effect) the quantity of tested bolts was reduced to limit the number of tests and time needed. As a result, for this second phase, the following were tested with up to 13 additional tightening and untightening cycles:

- 2 bolts corresponding to the maximum friction coefficient after 5 cycles
- 2 bolts corresponding to the minimum friction coefficient after 5 cycles
- 1 bolt corresponding to the average friction coefficient after 5 cycles

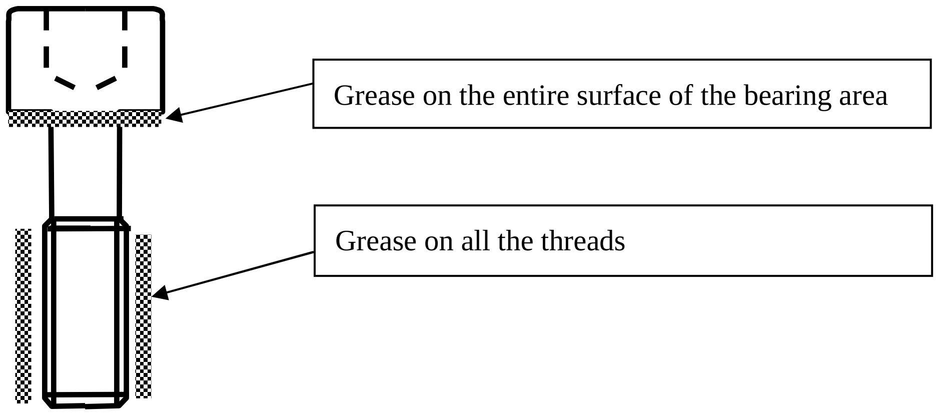

Figure 4 Greased zones

Test configurations

Three test configurations corresponding to a given TN cask closure system are presented below.

Test Configuration			
Bolt dimensions	M42	M42	M14
Bolt material	Carbon steel	Carbon steel	Carbon steel
Bolt coating	Electroplated Zinc	Electroplated Zinc	Electroplated Zinc
Washer material	Martensitic stainless steel	Martensitic stainless steel	Martensitic stainless steel
Thread material	Carbon steel	Carbon steel	Carbon steel
Maximum nominal torque	2000 N.m	1500 N.m	90 N.m
Greased	Yes	Yes	Yes

Test Results

For the M42 bolts in carbon steel threads with a torque of 2000 N.m (Figure 5), the measurements show that the maximum value is 16% above the average value for the first 5 tightening cycles and the minimum value is 15% below the average. The first 5 cycles are the most scattered. They are conservative regarding the dispersion of the friction coefficient during further cycles. The maximum value is reduced over the next tightening cycles but for the mimimum value there is no significant change. The dispersion of the tension is reduced starting from the fifth cycle.

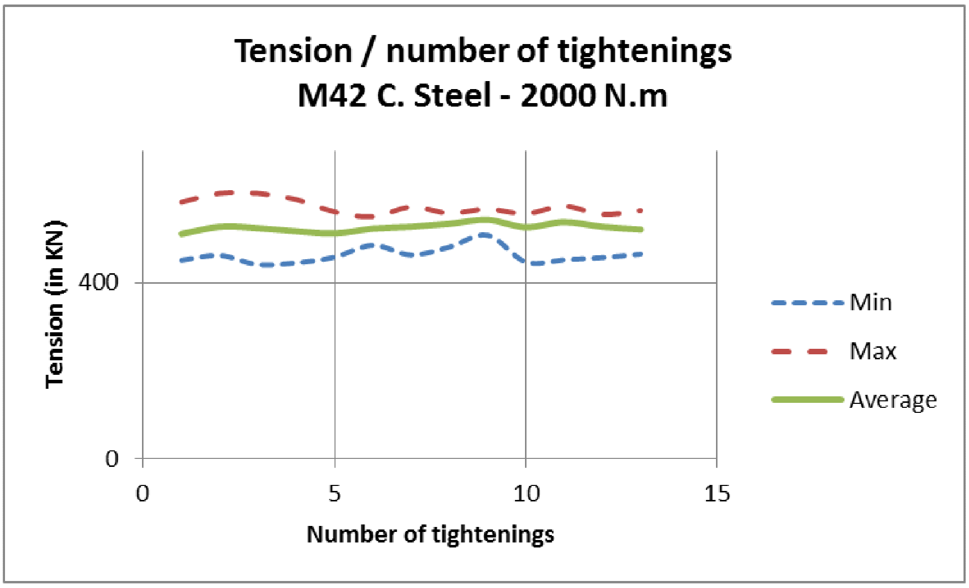

Figure 5 Preload variation for M42 bolt in carbon steel - 2000 N.m Torque

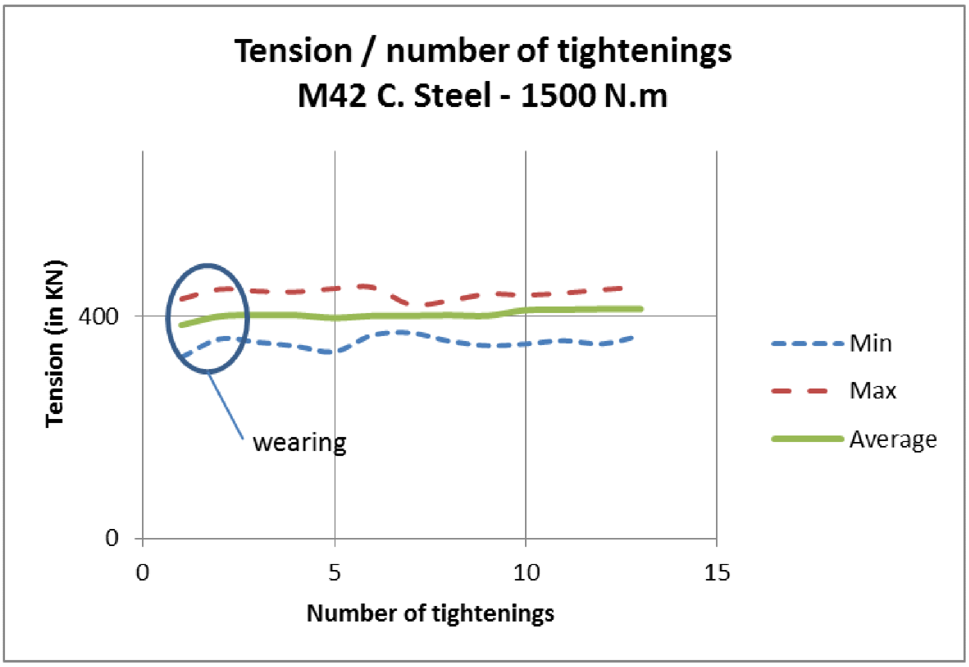

Figure 6 Preload variations for M42 bolt in carbon steel - 1500 N.m Torque

For the M42 bolts with carbon steel threads with a torque of 1500 N.m (Figure 6) the maximum value is 13% above the average value for the first 5 tightening cycles and the minimum value is 18% below the average. The first 5 tightenings are also the most scattered. They give an adequate evaluation of the variation. It can also be noticed that during the first tightening there is a wearing effect which results in a small increase of the preload for this configuration.

In the case of M42 bolts the friction coefficient maximum value with a tightening torque of 2000 N.m in carbon steel is 25% above the average value of the first 5 tightening cycles and the minimum value is 17% below the average (Figure 7).

For M42 bolts with a reduced tightening torque of 1500 N.m in carbon steel the maximum value is 24% above the average value of the first 5 tightening cycles and the minimum value is 14% below the average (Figure 8).

The comparison of the friction coefficient for a tightening torque of 2000 N.m to a tightening torque of 1500 N.m shows that they are quite the same (Figure 9). On the basis of these results, it can be considered that the torque value for this specific fastening configuration impacts neither the friction coefficient nor the related dispersion.

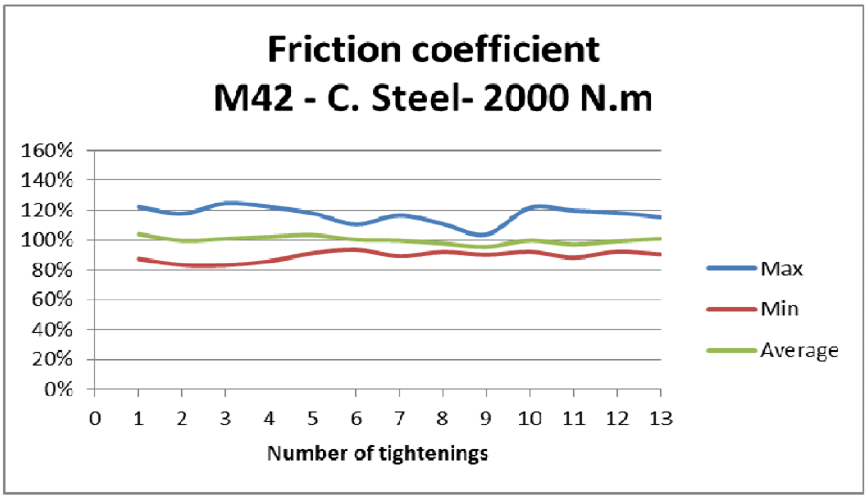

Figure 7 Friction coefficient - M42 bolts in carbon steel - 2000 N.m Torque

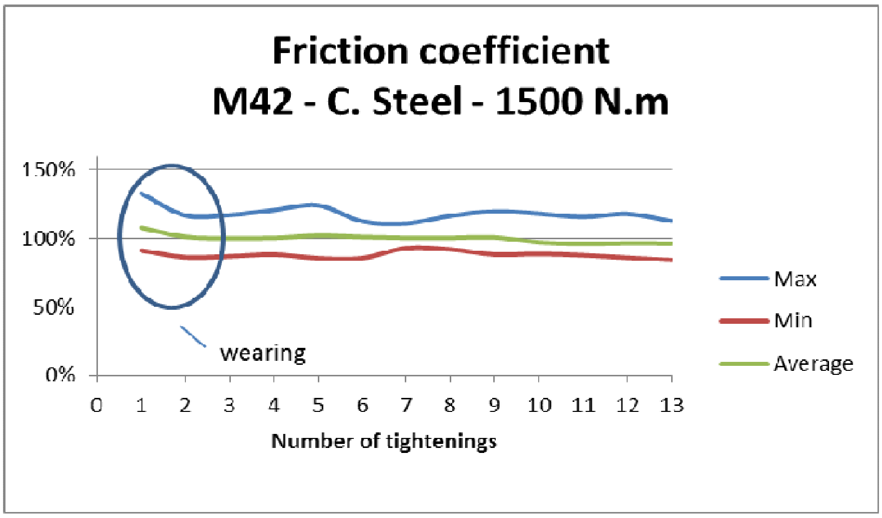

Figure 8 Friction coefficient - M42 bolts in carbon steel - 1500 N.m Torque

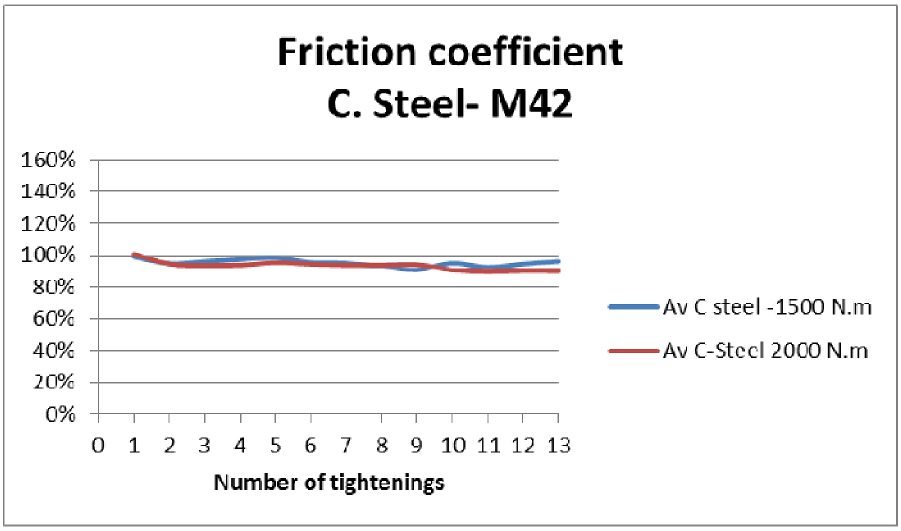

Figure 9 Friction coefficient - M42 bolts

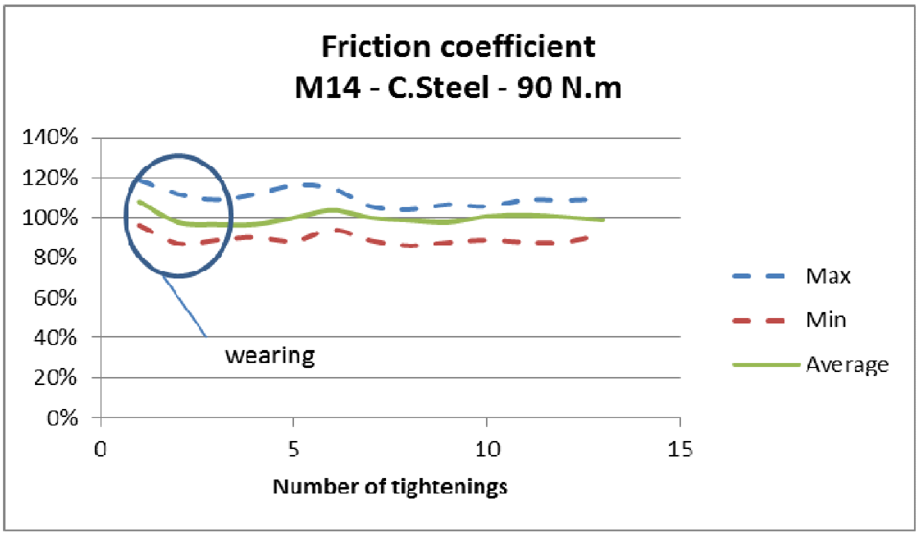

Figure 10 Friction coefficient for M14 in carbon steel - 90 N.m Torque

For the M14 bolts with a tightening torque of 90 N.m the friction coefficient value also decreases with the first tightening cycle. The coefficient maximum value is 16% above the average value of the first 5 tightening cycles and the minimum value is 13% below the average (Figure 10). There is a wearing effect similar to that of the M42 bolts. The average friction for M14 is 22% higher than that for M42.

Based on these measurements, if the same friction coefficient is to be considered for the M14 and M42 bolt analysis, a variation of the friction coefficient of at least +/- 27.5 % must be taken into account to bound all possible configurations.

Conclusions

During the very first tightening, there is a significant wearing effect due to the friction of the surfaces in contact. The degree of this wearing effect depends on the torque level, the nature of the lubricant, and the nature of the materials in contact. For subsequent tightening sequences, this wearing effect has no consequence on the dispersion of the friction coefficient as it is no longer visible after 5 cycles and the dispersion decreases.

Hence, for testing the friction coefficient of a given configuration 5 tightening cycles are sufficient as they are the most scattered with regard to the dispersion of the friction coefficient.

As for the test results, a robust bolted closure system should take into consideration a variation greater than +/-27.5% of the friction coefficient. Further reduction of the variation on the preload can be achieved by testing the friction coefficient for each specific configuration and by taking into account the wearing of the bolts.

References

ISO 16047:2005, "Fasteners – Torque/clamp force testing"