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Experimental Investigation of Friction Relations in Threaded Joints

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Abstract. This paper shows some of the results of the measurements of friction coefficients in stainless steel threads. Three different coatings of the used nuts are considered and tested under various axial loads. The friction conditions for coated standard nuts of M12 and M16 size were measured on a simple test stand. The resulting friction coefficients are plotted with respect to applied load for and pressure in the thread. The results are discussed in detail.

Introduction

The nowadays common use of stainless steel bolts and nuts brought some advantages as well as some disadvantages. The advantage evidently is the corrosion resistance of the connecting parts, which significantly reduces the necessary maintenance costs and prolongates the life cycle of the threaded joints. Besides of the higher price of stainless steel parts (compared to the standard steel), one of the notable disadvantages is in the worsening of friction conditions in the threaded joint. In general higher friction coefficients are typical for stainless steel parts rather than for the parts made of classical steel. This may cause higher tightening moments (up to seizing of the joint) resulting into a reduction of the exerted axial force in the threaded joints, leading to failure of the joint.

In order to overcome this issue, various lubricants or coatings can be applied to the contact surfaces of bolts and nuts ([1], [2], [3]). It was shown, that the use of liquid lubricant, various types of grease or solid lubricants can have positive effect on reduction of friction forces (coefficients) as well as to improve the corrosion resistance of the connecting parts (bolts and nuts). The application of such lubricants on the sliding parts is however connected with certain difficulties especially in outdoor conditions. Also the efficiency of such lubrication degrades quite quickly in time under extreme weather conditions. This is why often the use of solid coatings is recommended in such situations. There exist many different types of suitable coatings. Traditionally they were often formed by a thin layer (single or multiple) of metal (zinc, nickel, chrome, tin, silver, etc.). More recently the modern plastic materials (fluorplastics, like e.g polytetrafluoretylene PTFE, fluorinated ethylene propylene FEP, polyetylene PE, etc.) are able to form a coating layers providing sufficient protection against corrosion and to guarantee optimal friction properties at the same time. Alternatively a special surface treatment can be applied to friction surfaces, based on kind of dry paints, in which solid lubricant particles are dispersed. From the tribological point of view, all these coatings help to prevent the direct contact of the mechanical parts and to avoid dry friction between them.

This kind of coating treatment of connecting parts is of interest e.g. in pipeline repairs using clamps that are fixed using nuts and bolts. These are often made of stainless steel due to its high corrosion resistance needed for the pipes placed under the ground. The difficult conditions of outdoor repairs, including the montage and tightening of clamps, justifies the use of coated connecting parts [5].

The aim of this contribution is to bring some insight into the evaluation of the friction properties of these coatings in threaded joints, with special focus on their degradation by excessive wear under high axial loads.

Experimental setup

The goal of the experiments was to test several bolt/nut couples, subject to different surface treatment, under static axial load(s) during the tightening/loosening of the joint. The test setup consisted from a fixed nut (treated with coating), through the which a bolt (stainless, uncoated) is screwed. The applied moment is measured using the T20WN/20 Nm sensor, from the Hottinger Baldwin Messtechnik GmbH company, calibrated using the torsion moment wrench TMK 200. During the measurement, the bolt was turned continuously, slowly until the value of the moment reached a stable value. The measuring sensor was connected to a computer, recording the time evolution (sequence) of the moment. Based on this record, the stabilized mean value of the moment was determined (using the LABVIEW software package) for each specific case.

During the measurement the bolt was oriented vertically (head up), with the load attached to its free end below the nut. Series of weights was attached to the bolt to study the friction conditions and parameters under different loads. The mass of the applied loads was approximately 83, 162, 202 and 246 kilograms.

The bolt was screwed first down, by turning it to the right, through the (new, coated) nut, while the load weight increased sequentially (4 different weights were attached), and then back up (turning it to the left), taking the weights off again from the end of the bolt. In order to evaluate the effects of the wear of the various coatings, the same experiment was repeated with the nuts that have been previously used. The whole series of measurements was performed independently for M12 and M16 nuts/bolts. See e.g. [4], [5] for details.

Experimental results

Three different coatings of nuts were tested in a series of the above described experiments. The Coating A is zinc, typically used to increase the corrosion resistance of nuts made of standard steel. Coating B is based on PTFE (Polytetrafluoroethylene), while Coating C is a dry sliding paint with molybden suplhide additive. The types of studied coatings, including some of their essential properties are summarized in the table 1.

Tab. 1 Types of applied coatings and their declared properties

Coating	*Type*	*Thickness [μm]*	*Friction coef. [1]*
A	zinc based *(Delta Tone)*	4-10	0.09-0.14
B	PTFE based (Polytetrafluoroethylene) *(Xylan)*	20-35	0.02-0.2
C	dry sliding paint with molybden suplhide (MoS_2) additive *(Gleitmo)*	3-5	0.05-0.1

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As mentioned above, the moment needed to turn the bolt was measured for different axial loads (attached weights), different directions of the bolt movement (up/down) and different thread sizes (M12/M16), always for new and reused nuts. Based on the measured moment, the friction coefficient was evaluated for each case using the formula

$$f = \left(\frac{2M_k}{Qd_2} - tan\gamma\right) cos\beta \quad (1)$$

where Q is axial load, d_2 is pitch diameter of nut thread, M_k is the applied moment, γ is the thread lead angle and β denotes the (half) angle of the thread profile. From the below presented results, i.e. the friction coefficients shown in figures 1-3, is evident that the reused nuts (marked by dashed lines) typically exhibit much higher friction when compared to the new ones (marked by a solid line). This trend is obvious, although its intensity is not the same for all the three studied coatings. This observed phenomena might be caused by the wear of the coating, due to an excessive load in the thread. However this hypothesis has to be verified, for which the presented results should serve as a starting point.

In general the friction forces are proportional to applied loading force, thus this load naturally appears as the independent variable in the graphs presenting the obtained friction coefficients. Because the same load weights were used for all coating and both sizes of the nuts, the horizontal scale is the same for both M12 and M16 nuts. This form of visualization is shown in the left part of the figures 1-3.

However considering the expected wear of the coatings in the threads of the nuts, the contact pressure in the threads can play an important role. Thus, in the right pat of the figures, the same dependence of friction coefficients is always plotted with respect to the corresponding pressure in the thread. The pressure in the thread is computed from

$$p = \frac{Q}{\pi d_2 H_1 z}, \quad (2)$$

where p is pressure in the thread, H_1 is height of the thread profile with rounded crests and roots while z is the number of support thread. See e.g. [6], [7], [8] for more details.

Because the M16 threads have larger contact surface, the resulting contact pressure is lower (for the same force Q) than while using the smaller M12 nuts. This is why the corresponding range of contact pressures is different for M12 and M16 threads, despite of using the same axial loads. The M16 curves seem now like shifted towards the lower pressures.

The results obtained for the classical zinc based coating are drawn in the figure 1, showing the friction coefficients dependence on both, the axial loading force Q and the resulting contact pressure p.

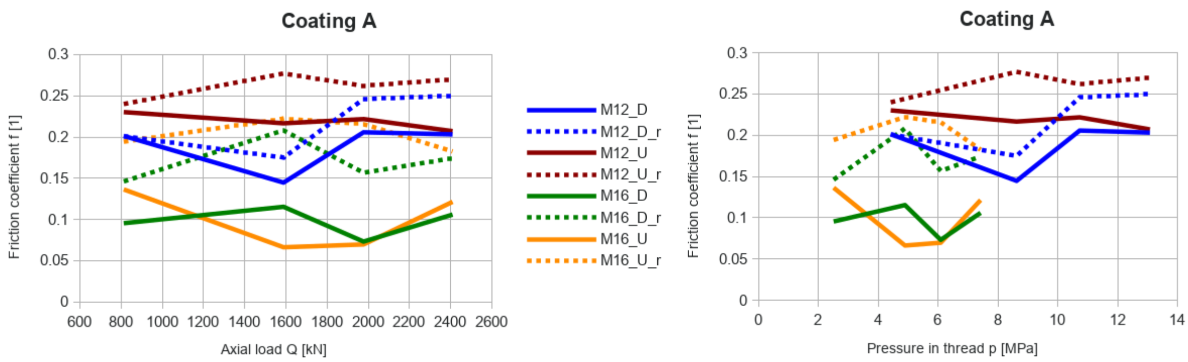

Fig 3 Friction dependence on axial load and pressure in the thread for coating A

In the figure 1, for the zinc coating A, it is obvious that not only the friction coefficients are higher for the reused nuts, but also that the friction coefficients are significantly lower in the larger M16 threads where the range of contact pressures is lower compared with the smaller M12 thread.

The results in the figure 2 for the plastic, PTFE based coating B show similar trend for new versus reused nuts, with higher overall friction in the reused nuts. On the other hand, the friction coefficients for this kind of coating seem to be much less dependent on the pressure in the thread. It should be noted however that the average friction coefficient is visibly higher for this coating in comparison with the previous type A coating based on zinc.

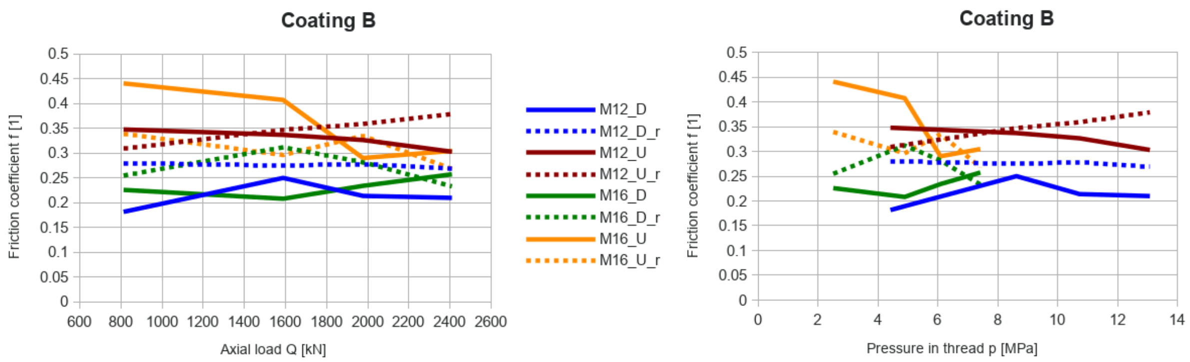

Fig 4 Friction dependence on axial load and pressure in the thread for coating B

The sliding paint, marked as coating C, exhibits yet another kind of behavior. As it can be seen in the figure 3, the friction coefficients are in this case quite insensitive to the variation of the pressure in the thread, however the difference between the new and reused nuts is significant. The friction coefficients in reused nuts are about 2-3 times higher than in the new nuts.

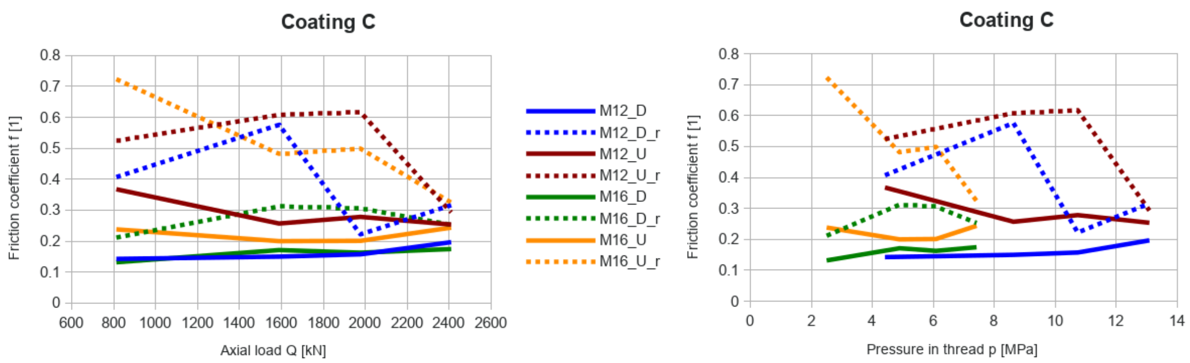

Fig 5 Friction dependence on axial load and pressure in the thread for coating C

Due to this elevated friction in the reused nuts, the overall friction coefficients values are higher than for the previous two coatings A and B. This however strongly depends on the previous use of the nuts.

Conclusions

Our experimental investigation has confirmed that the use of coating of nuts has significant impact on the friction coefficients in thread. The measured friction coefficients for the new nuts were found in (or close to) the range declared by the producers of the coating (see table 1). The reused nuts however show significantly higher friction coefficients close to those found for untreated, raw stainless steel dry surface contact.

The reduction of friction can lead to lower tightening moments needed to ensure the required axial force in the joint. The recommendation of the use of specific surface treatment should however take into account the repeated assembly/disassembly of the joint as well as the level of the contact pressure in the thread, that can lead to excessive wear of the coating and the degradation of its friction properties. The dependence of the coating wear on the contact pressure should further be studied in detail to confirm and possibly better explain the physical mechanisms being responsible for it. The preliminary evaluation of available microphotographs of the sample nuts shows significant reduction of the thickness of the coating layers on the sliding surface of the threads. Thus the thickness of different coatings (shown in the table 1) can be the one of the other crucial factors in prediction of the wear of different types of coatings. This direction of investigation will be followed in our future work.

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