EAN 2017
55th conference on experimental stress analysis

Remark on repairing broken pipelines

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Introduction

Broken pipelines can be repaired in different ways. The standard procedure is to simply replace the damaged segment of the pipe. However, it is usually quite expensive solution requiring non-negligible human and financial resources. Instead, in certain cases, much cheaper and faster solution is available. It is based on the use of repair clamps, such as e. g. in the Figure 1. In the case this repair clamp is properly chosen and mounted, it can last for many years, almost as long as if the pipe segment has been completely exchanged.

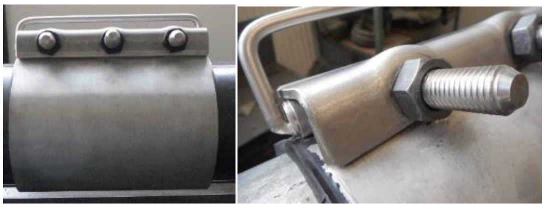

Fig. 1. Example of a repair clamp and the tightening screwed joint - Laboratories of the Faculty of Mechanical Engineering CTU in Prague.

Unfortunately, this type of repair procedure also has certain limitations. The grip force in the repair clamp is ensured by a stainless steel screwed joint (screw and nut). The use of austenitic stainless steel for connecting parts can however cause some problems, due to higher friction coefficient causing the joint seizure. To improve the friction properties during the assembly, specific types of coatings or dry lubricants can be applied. Despite of using stainless steel parts, some kind of additional protective cover is necessary to avoid problems arising due to microbiological corrosion in the ground. In addition, prior to pipeline use, careful anti-leak tests have to be performed in site.

In order to find the optimal combination of connecting parts, their coatings-lubricants, a series of experiments was performed to analyze the torque required for tightening and loosening the screw connections. Two sizes of threads were considered together with various surface finishes of the nut thread. It was found that tested coatings significantly reduce the friction coefficient in the threaded joint, facilitate the assembly and also increase the corrosion resistance in the extremely aggressive corrosive environment (due to Sulphur, chlorine or microbiological effects). Some experiments were also performed in order to determine the friction coefficient in the threaded joints.

Such measurements of screwed joints are very expensive and time-consuming. Therefore the experiments were only performed on an economically reasonably sized sample group. The results of these tests are presented hereafter, accompanied by a short analysis of the structure of the corresponding measurements costs.

The tests have confirmed the justification of the replacement of coated nuts by uncoated ones. However, the price of the coated parts is about 30% higher than the standard, uncoated ones [5], [6], [7].

Measurement methodology

To ensure the consistency of acquired data, specific measurement methodology had to be designed. This task was quite time consuming, as the appropriate measurement approach had to be chosen to guarantee the desired accuracy and completeness of the data. Preparation of the draft of the methodology took about 8 hours to an experienced professor. During this time it was necessary to choose the measuring apparatus, design suitable fixtures, measuring tools and instruments required to perform the whole experimental task. Experimental workplace and measuring stand are shown in the Figure 2.

During the experiment, the following parameters were *monitored*:

- Axial force in bolts.
- Applied torque.
- Type of the coating.
- Type of the lubricant.

Based on the measured data, the following additional quantities were *calculated*:

- Friction angle of the thread.
- Coefficient of friction in the thread.
- Friction angle for the tribological pair (combinations of materials, conditions of sliding friction and surfaces).
- Coefficient of friction for the tribological pair (the combination of material conditions of sliding friction and surfaces) [2], [3].

Fig. 2. Details of experimental measuring stand - Laboratories of the Faculty of Mechanical Engineering CTU in Prague.

Before the actual measurement started, the screwed joints had to be prepared at the test stand. These activities took roughly 90 minutes. The preparatory phase of the measurements included, among others, preparation of recording sheets (measurement tables), preparation of weights for given measurement, etc. To ensure the accuracy of the measurements, the torque sensor had to be calibrated in a time-frame of 5 minutes. Generally, one measurement usually took about 40 minutes. Since two sizes of matrices were tested (M12 and M16), the time for their exchange, taking approximately 5 minutes, has to be considered as well. In summary, the actual measurements lasted for 5 days, typically 8 hours per day. This time includes the preparatory phase, sensor calibration and instruments cleaning after the measurement.

Overall costs breakdown

The overall costs include:

1. Consumption of material (laboratory gloves and overalls, cleaning material, DVDs for storing data, etc.)
2. Production services (clamping device production).
3. Nonproduction services (assembly, installation software and verification of the testing equipment).
4. Depreciation of tools and machines used.
5. Personal costs including the salaries, that can be further quantified according to the time requirements described above.
6. Taxes and fees.
7. Financial expenses.

Economic issues in detail

- The selection of suitable machines and instruments needed for each measurement took about 8 hours of time to an assistant professor.
- Manufacturing and preparation of the test fixtures needed for the measurements took (on average) 8 hours of time to a skilled worker.
- Preparation of the experimental facility and its testing took approximately 1 hour, being done by three investigators.
- The actual measurement, i.e. data capturing, took about 16 hours, being performed by three investigators.
- Data preprocessing, i.e. sorting, editing and transformation for further analysis took (on average) 16 hours. This work has handled by three investigators.
- Data analysis, post processing and writing of the final report took about 40 hours of a joint work of three lecturers.

Remarks on model for measurements

The basic set of measurements contained 16 nuts. They were evaluated in two sizes, M12 and M16. In the second part of measurements, it was possible to determine the damage of the coating of various nuts.

According to the theory, the torque should increase linearly depending on the axial force in the bolt, considering the constant friction coefficients in the thread (see equation (1))[3].

$$M_{KK} = M_K + M_{TH} = Q_o \cdot \frac{d_2}{2} \cdot tg(\gamma + \varphi') + Q_o \cdot \rho_{TH} \cdot f_{TH} \quad (1)$$

In our case, the coefficient of friction in the thread changes with the load (see Figures 3-10). This is probably due to a variable quality of the surface of the thread, abrasion of the applied coating and a non-uniform speed of nuts tightening (manual assembly).

From the torque depending on the axial force, see the diagrams in Figure 3 and Figure 4, it is possible to compare the size of the friction coefficients of the screw connections with fixed coatings versus those where the lubricating grease was used. The best is the case in which the measured torque achieves its lowest value. Less energy is consumed to overcome the friction in the thread during the tightening. The assembly is easier and at the same time a higher axial pretension is achieved in the screw joint, thus the connecting clamp provides the maximum sealing capability [1], [2], [4].

Conclusions

From the Table 1 it is evident that from the experiments performed on the M16 sized nuts, in case of using new as well as re-used (after one use) stainless nuts, the best is the performance of nuts with the Coating A. In the case of new nuts the Coating C (sliding paint) works quite well, and the lubricated stainless steel nuts (using good quality lubricating grease) are also an acceptable option.

This conclusion is also documented by the Fig. 3 and 4, showing the torque necessary for lifting and lowering the weights during individual experiments. The best choice requiring the lowest torque for M16 nuts is again Coating A. In the case of new nuts the Coating C (sliding paint) seems to be the best, but the new stainless steel nuts can equally be treated by a good quality lubricant (e.g. graphite grease).

Variant Nut A4-80	**Friction coefficient-theoretical**	**Friction coefficient – measured (M16)**	**Friction coefficient – measured (M12)**
Coating A zinc (corrosion-proof)	**0.09 - 0.14**	0.097	0.204
Coating A (re-used nut) zinc (corrosion-proof)		0.188	0.240
Coating B - based on PTFE (Polytetrafluorethylene)	**0.02 - 0.2**	0.296	0.271
Coating B (re-used nut) based on PTFE (Polytetrafluorethylene)		0.290	0.312
Coating C - dry sliding paint with molybden suplhide additive	**0.05 - 0.1**	0.190	0.225
Coating C (re-used) - dry sliding paint with molybden suplhide additive		0.389	0.445
Stainless nut		0.401	0.553
Stainless nut with graphite grease		0.250	0.202

Tab. 1. Summary of the experimentally determined initial values of the friction coefficient ***f*** for the tested and reference M16 and M12 nuts. [2]

It is apparent from the Table 1, that from the experiments performed on the M12 nuts, in the case of using new stainless nuts, the best choice seems to be the use of good quality lubricant (e.g. graphite grease), or alternatively, the Coating A can provide a good performance for both new and re-used nuts. For new nuts, the Coating C is also acceptable.

Similar conclusion can be drawn from the Fig 5 and 6, showing the torque necessary for lifting and lowering the weights during individual experiments. The best choice, requiring the lowest torque, for the case of M12 nuts is again the combination of stainless nut with suitable lubricant, followed by the nuts with Coating A as the second choice and nuts with Coating C at the third place.

The essential finding is the fact that in all cases, on the working surfaces of the threads of used nuts (i.e. after being used for one mounting of the repair fixture), there was observed marked abrasive wear of the applied coatings (as well as of the sliding paint), often accompanied by the deformation (plastization) of the working surface of the thread of the nut. Due to high values of contact pressures in the threaded surfaces of the bolts and nuts during their mutual relative motion in the course of the assembly (tightening) of the screwed joint, there appears an intensive abrasion of the coating (and paint). In all cases the whole coating (paint) layer was rubbed off from the used nuts.

Significant abrasion of the used nuts coating was also visible on the annulus contact surfaces of nuts. This effect was also observed during the disassembly of the test joints of repair clamps, where appeared "scurfs" of the coating rubbed off from the bearing surfaces of the nuts. Traces of the rubbed of coating were also found in the threaded surfaces of the stainless bolt after the disassembly of the joint.

As a conclusion, it's possible to say that the positive properties of the studied coatings can only improve the mounting behaviour of the screwed joints till the moment, when the coating layer is rubbed off, i.e. till the beginning of the mounting (tightening) process. During the final stage of the screwed joint tightening, the friction properties of the tribological pair will be significantly worse.

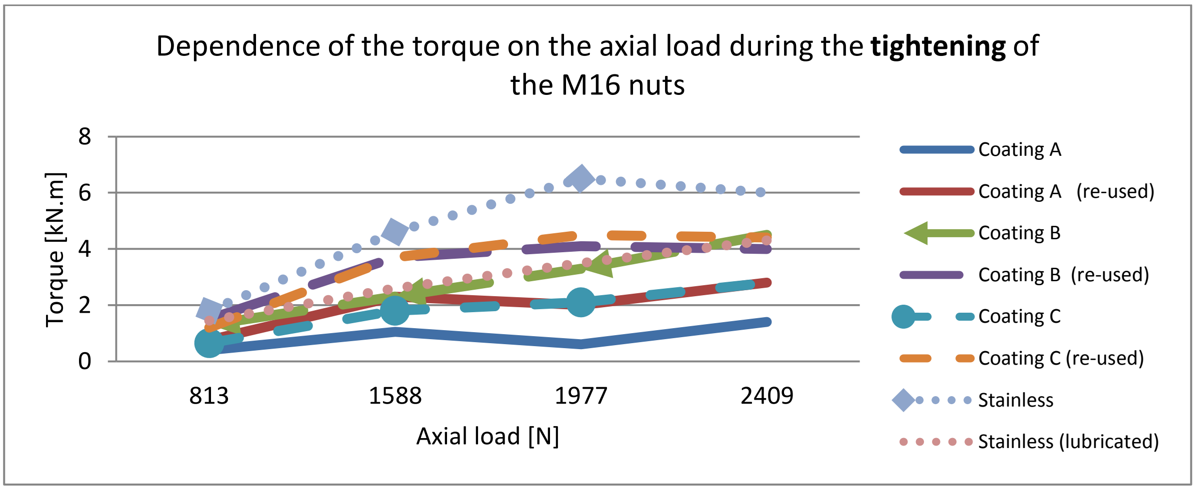

Fig. 3. Dependence of the torque on the axial load during the **tightening** of the M16 nuts.

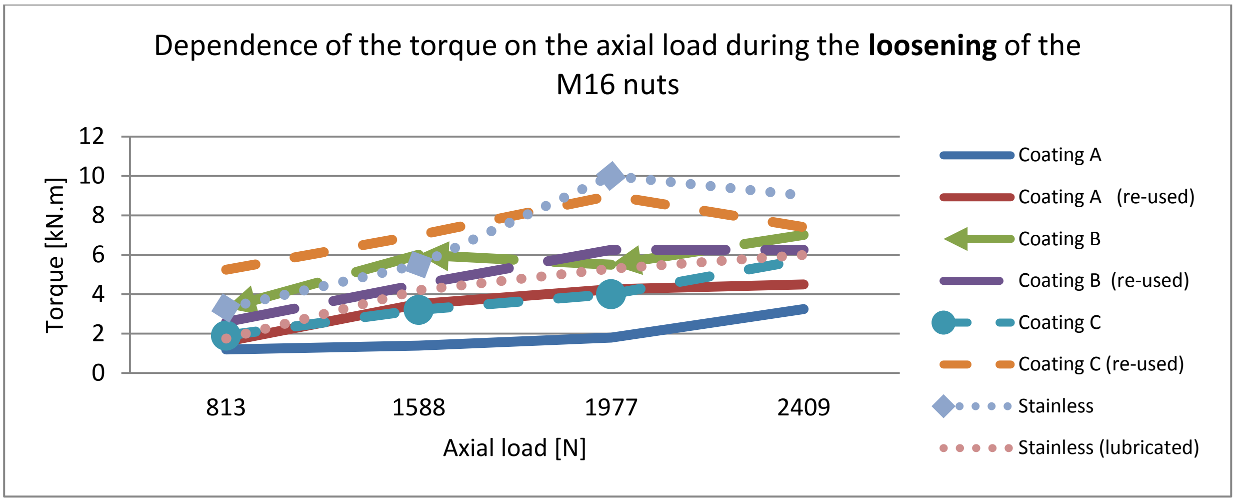

Fig. 4. Dependence of the torque on the axial load during the **loosening** of the M16 nuts.

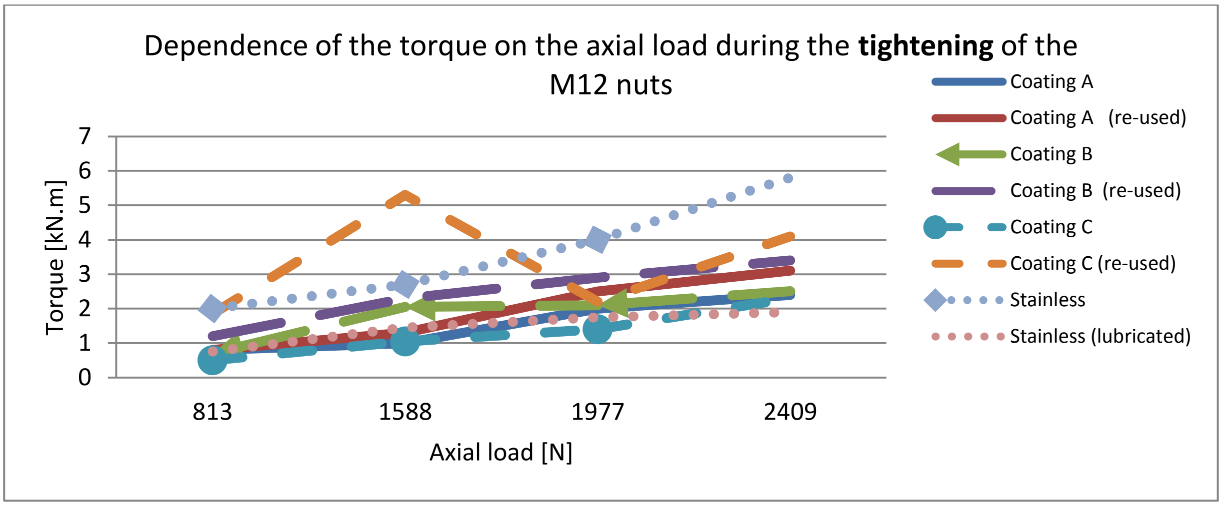

Fig. 5. Dependence of the torque on the axial load during the **tightening** of the M12 nuts.

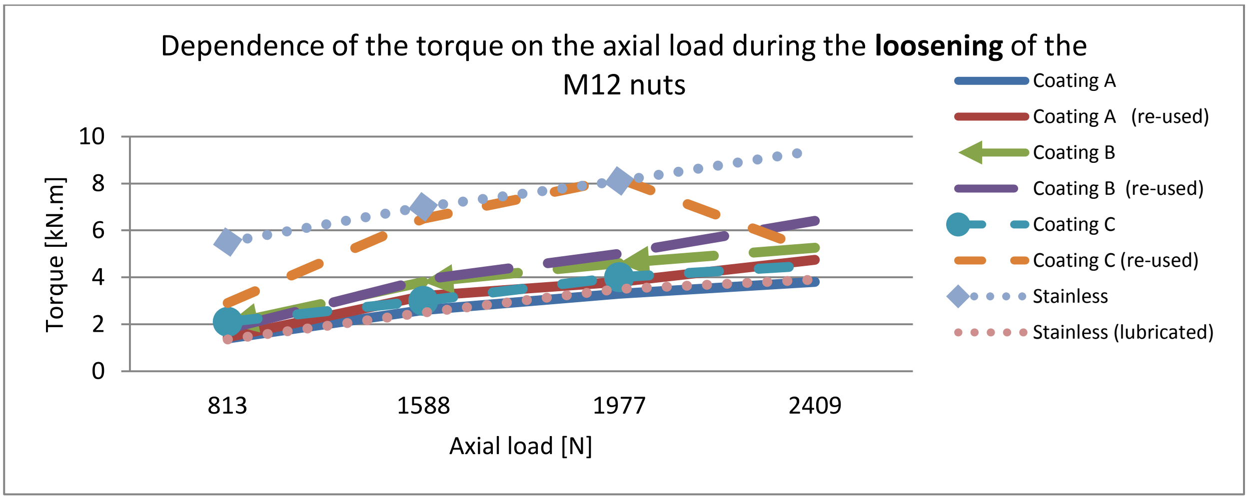

Fig. 6. Dependence of the torque on the axial load during the **loosening** of the M12 nuts.

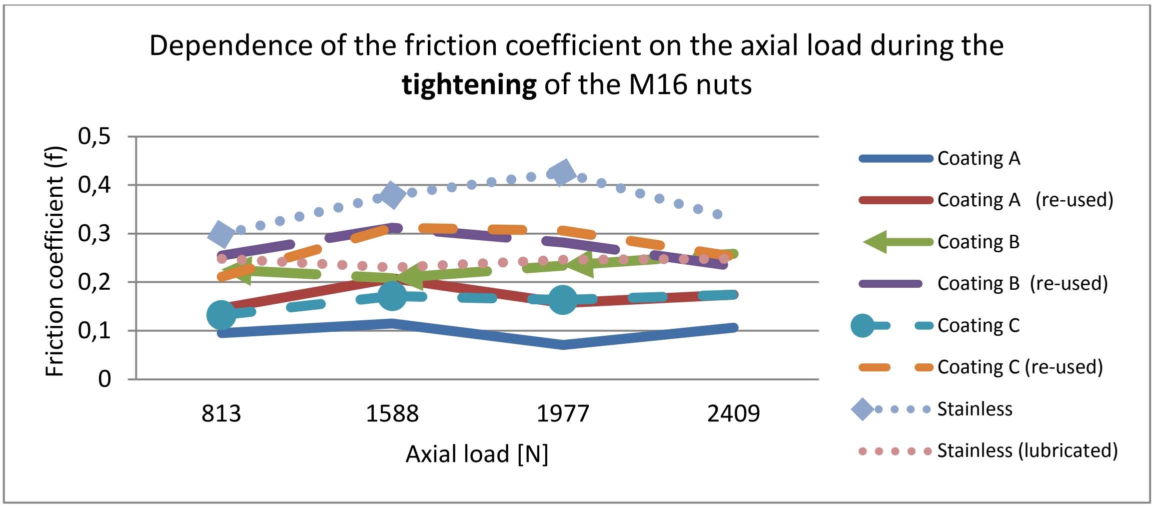

Fig. 7. Dependence of the friction coefficient on the axial load during the **tightening** of the M16 nuts.

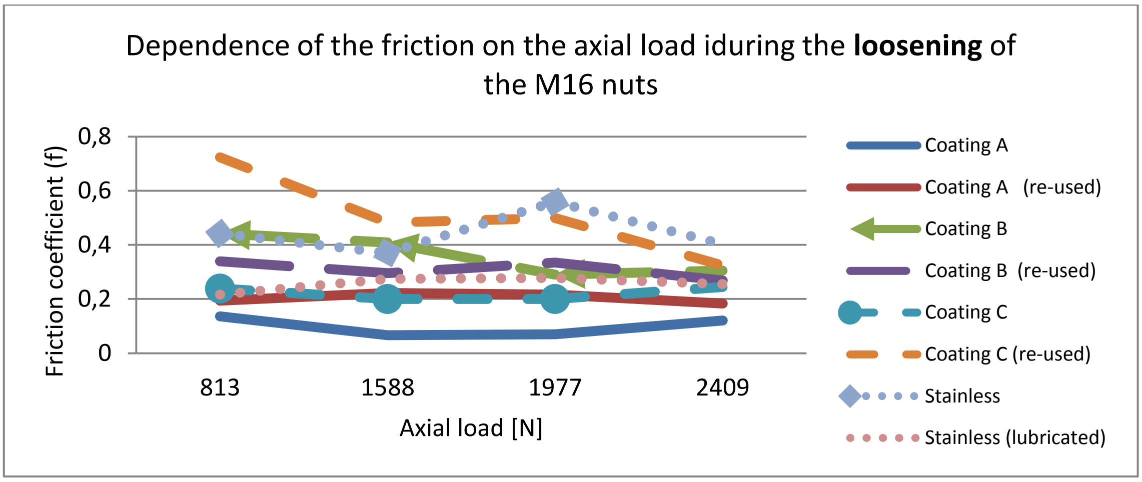

Fig. 8. Dependence of the friction coefficient on the axial load during the **loosening** of the M16 nuts.

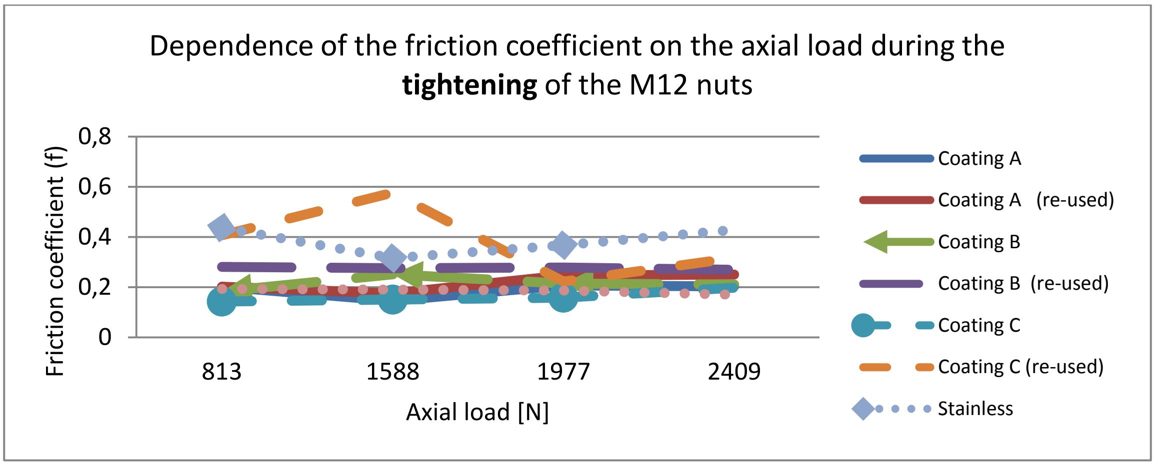

Fig. 9. Dependence of the friction coefficient on the axial force during the **tightening** of the M12 nuts.

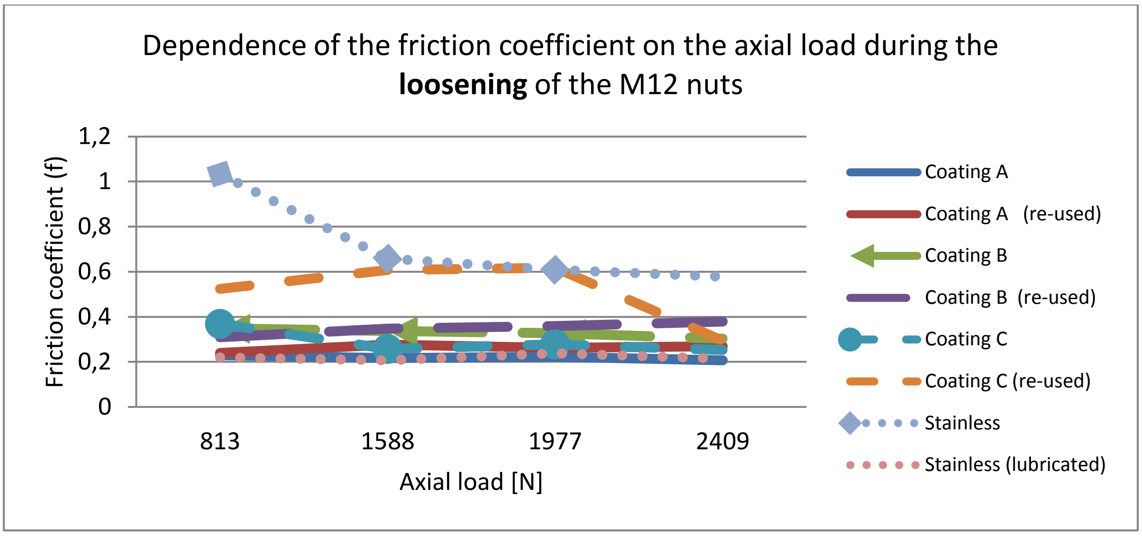

Fig. 10. Dependence of the friction coefficient on the axial load during the **loosening** of the M12 nuts.

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