

Full paper

Influence of Lubrication on High-Strength Friction Grip Bolts: Bolt Tightening

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Abstract

High-Strength Friction Grip (HSFG) bolts of grade 8.8 are widely used in structural steel connections due to their high strength and ability to achieve significant clamping force through pre-tensioning. However, the performance of these bolts is dependent on the tightening process. Among the key influencing factors, the type of lubricant used, and the method of its application play a role in the installation process. At present, New Zealand, European, and several other international standards do not provide explicit guidance on the selection of lubricants or on standardized lubrication procedures for HSFG bolts. In practice, contractors often adopt different lubrication approaches depending on project-specific conditions, leading to inconsistencies in bolting quality control before and during installation. This study presents an experimental investigation into the influence of lubrication on the behaviour of grade 8.8 HSFG bolts tightened using the part-turn method specified in NZS 3404. Three categories of lubricants were examined: factory-applied lubricants, site-applied lubricants, and other commonly used lubricants. In addition, three lubrication regimes were considered: nut-only lubrication, thread-only lubrication, and full lubrication covering both nut and thread. Based on the experimental results, this study identifies lubricants that are more consistent tightening behaviour and reduced torque scatter and proposes a practical lubrication procedure to improve bolting quality control during installation.

Keywords

Bolting, Bolted Connections, HSFG Bolts, Lubricant, Preload, Torque

1 Introduction

High-Strength Friction Grip (HSFG) bolts are extensively used in steel structures due to their ability to provide high level of preload, high strength when used in tension-bearing connections, and reliable load transfer through friction at the faying surfaces. The structural performance of HSFG bolted connections is dependent on the level of bolt preload achieved during installation as one of the key factors, however, this performance also requires strict control of bolt tightening force and factors affecting it. Both insufficient and excessive tightening can impact the behaviour and possibly the load-bearing capacity of the connection, thereby affecting the durability and performance of the structure. Consequently, ensuring that the intended preload is consistently achieved on site is an important aspect

of bolting quality control.

In practice, the preload in HSFG bolts is generated through controlled tightening procedures, such as the part-turn method and the direct tension indicator (DTI) method specified in the New Zealand Steel Structures Standard NZS 3404 [1]. The DTI method, which uses devices such as DTI washers (such as DTI Squirter Washer) or bolts with tension-indicating heads (such as DTI Smart Bolt), allows for determining if the actual tension achieved in the bolt after tightening. This method also requires specialized equipment and is typically applied in situations where higher accuracy of bolt tension is required. On the other hand, the part-turn method involves a two-step process. First, a snug-tight step is applied (all bolts in the connection are tightened until the faying surfaces are brought

into firm contact). Then, the nuts (or bolt head in some cases) are turned further by a specified angle, typically one-quarter or one-third of a turn, depending on the bolt length-to-diameter ratio and the surface interface conditions. According to NZS 3404 [1], the torque-control method of tightening is allowed mainly for inspection and not as the primary method of tightening, and the use of DTIs instead of the part-turn method of tightening is allowed only under specific circumstances. There are other structural standards which have specified and allowed torque-control, the use of DTIs, or other methods of tightening, e.g. [2,3,4].

These procedures rely on assumptions regarding the frictional behaviour of the bolt assembly, including friction at the threads and under the nut bearing surface. Among the factors influencing friction, lubrication plays a significant role. Variations in lubricant type, application method, and lubrication location can alter the torque-tension relationship, leading to variations in the installation torque required to achieve the intended preload [5-12]. Although the part turn method of tightening does not directly depend on torque, the excessive torque during applying the part-turn may result in higher demands on the bolt, thereby affecting their long-term performance, and in some cases even the achieved preload.

Despite the importance of lubrication, current New Zealand, European, and several other international standards do not provide explicit guidance on the type of lubricant to be used for HSFG bolts or on a standardised lubrication procedure. As a result, industry practice often varies between projects, with contractors adopting different lubricants and application methods based on experience, availability, or site-specific considerations. This lack of consistency introduces uncertainty in bolting performance and poses challenges for quality assurance and quality control during installation.

While preload is an important design parameter, direct measurement of bolt preload is rarely undertaken on construction sites. In the lab environment, tightening process can be assessed using digital torque-measuring devices such as smart sockets and specialized load cells to measure the preload. Analysis of installation torque, the preload, and their variabilities also provide valuable insight into the influence of lubrication on the reliability of achieving the target preload.

This paper investigates the influence of different lubricant types and lubrication regimes on the tightening behaviour of HSFG bolts installed using the part-turn method, and a smart socket to measure the torque value. By comparing the installation torque and its variability at two stages: at the attainment of the specified rotation angle and at bolt failure, the study aims to evaluate the effects of lubrication on torque required to apply the part-turn method, and to support the development of more consistent and practical installation procedures for HSFG bolted connections.

2 Background and Standards Review

The relationship between installation torque and bolt preload is governed primarily by friction at the thread interface and under the nut bearing surface. Additional sources of friction may also arise under the bolt head and at the

interfaces between the clamped plates. A considerable proportion of the applied torque is dissipated in overcoming friction, while only a relatively small fraction contributes directly to bolt elongation and preload generation [13]. Changes in friction conditions - particularly those resulting from lubrication - can lead to substantial variations in the torque required to achieve a given level of preload.

The part-turn method, as specified in NZS 3404 [1], is widely used for tightening HSFG bolts in New Zealand. This method is intended to reduce sensitivity to torque variability by controlling bolt elongation through a specified nut rotation beyond the snug-tight condition. Lubrication can still influence tightening behaviour in applying part-turn method, including the torque developed during rotation and the outcome of the tightening process [14-16]. Similar approaches are adopted in European and other international standards, where rotation-based tightening methods are recommended instead of or along with torque-controlled methods. Nevertheless, these standards also provide limited guidance on lubrication, often leaving the selection of lubricant type and application procedure to manufacturers or site practice.

For example, AS/NZS 1252 [17] requires that all coated and uncoated nuts be lubricated to prevent seizure during tightening, and that the lubricant be dry and clean to the touch; however, it does not specify the exact type of lubricant or detailed lubrication procedures. Similarly, BS EN 1090-2 [2] requires that high-strength bolting assemblies intended for preloading be used without alteration to the as-delivered lubrication and that assemblies be checked if the tightening process is delayed under uncontrolled exposure conditions, but it likewise does not specify the lubricant type or lubrication procedure. As a result, lubrication often remains an uncontrolled or poorly controlled variable in many bolting operations.

According to NZS 3404 [1], installation torque may be used as an inspection check, even when rotation-based tightening methods are employed. Modern smart socket systems enable continuous recording of torque during tightening, providing detailed information on tightening behaviour, peak torque demand, and variabilities between bolts. Although installation torque cannot be directly equated to installed bolt tension, trends in torque response and its scatter provide useful insight into the consistency and reliability of the tightening process.

In this context, examining the influence of lubrication on installation torque provides a practical means of evaluating bolting behaviour under realistic site conditions. This approach complements preload-focused studies and supports the development of improved guidance on lubrication practices for HSFG bolted connections.

3 Experimental Programme

As shown in Figure 1, a bolt-tightening test rig was designed and rigidly fixed to a test bench using a vice to simulate a typical structural bolted connection. Four M16 HSFG grade 8.8 bolts were initially snug-tightened. Subsequently, one of the four bolts was removed and replaced with the target bolt, which was used for testing under different configurations.

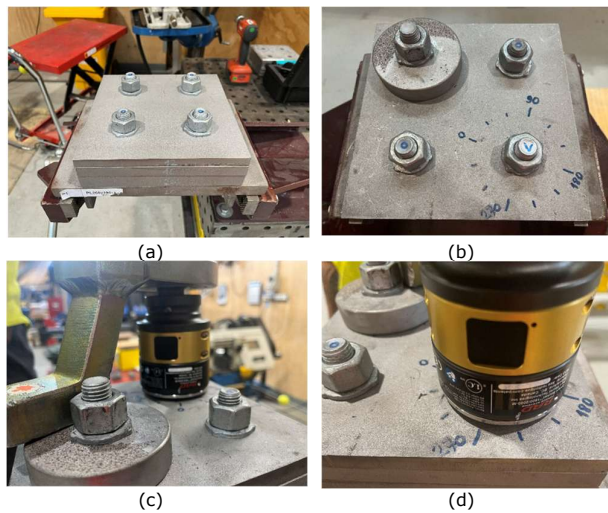


Figure 1 Bolt tightening test setup: a) Fixed plates using four M16 bolts, b) Target bolt replaced and in position, c) Smart socket installed on the target bolt and d) Rotation angle scale marked on the setup.

During the tightening experiments, the following parameters were monitored for each target bolt, from the snug-tight condition through to the full tensioning and then fracture.

- Applied torque on the nut measured by a smart socket.
- Nut rotation, visually monitored by marking the nut and measuring the rotation angle using an angle gauge.

3.1 Pre-test Inspection of Bolts

The experimental study was conducted on M16x130 HSFG bolts of grade 8.8. There were eight experimental conditions established as shown in Table 1, and each condition was assessed on three specimens. In total, twenty-four bolt samples were evaluated. Each bolt assembly consisted of a bolt, nut, and washers supplied in accordance with AS/NZS 1252 [16,17] and were purchased from a professional fastener supplier in New Zealand. All the received bolts were tested based on the “free turn of nut” check recommended by Ramhormozian et al. [14–16] and included in AS/NZS 1252.2 [18], which indicates: “Nuts shall run freely when part of a bolt/nut assembly. This shall be checked by running the nut along the bolt’s threads by hand the full length of the thread before being used in a connection. Only bolt/nut assemblies that pass this test shall be used. Once a bolt/nut assembly has been so tested, neither component shall be substituted.” All bolts have passed the “free turn of nut” requirement.

3.2 Lubricant Types

Three categories of lubricants were considered in this study:

- Factory-applied lubricants, as supplied by the bolt manufacturer which is known as a petroleum-based or water-soluble wax after applying a hot-dip galvanised (HDG) coating.
- Site-applied lubricants commonly used in practice (WS140 CRL), as shown in Figure 2.
- Other types of lubricants representative of non-standard or alternative site usage. The most used lubricant

is grease containing molybdenum disulfide (MoS_2), used as an anti-seize and anti-galling compounds under high contact pressure conditions. In this study, the selected lubricant was GA 50, which contains at least 50% MoS_2 , also shown in Figure 2.

The selected lubricants reflect a range of frictional characteristics and application practices observed in industry.



Figure 2 Lubricants applied in the experiment: GA 50 (top) and WS140 CRL (bottom).

3.3 Lubricant Regimes

For each lubricant type, three lubrication regimes were examined to assess the influence of lubricant location:

- Nut-only lubrication, where lubricant was applied to the nut bearing surface and threads inside the nut
- Thread-only lubrication, where lubricant was applied to the bolt threads
- Full lubrication, where lubricant was applied to both the nut bearing surface and the bolt threads.

The lubrication types and regimes are summarised in Table 1.

Table 1 Lubricant types and regimes

Bolt Designation	Coating	Lubricant type	Lubricant Regimes
M16x130	HDG	As supplied	Nut only
M16x130	HDG	As supplied	None
M16x130	HDG	GA 50	Nut only
M16x130	HDG	GA 50	Thread only
M16x130	HDG	GA 50	Nut and thread
M16x130	HDG	WS140 CRL	Nut only
M16x130	HDG	WS140 CRL	Thread only
M16x130	HDG	WS140 CRL	Nut and thread

Care was taken to apply lubrication in a consistent manner for all specimens within the same test group.

3.4 Test Procedure

The experimental procedure for each target bolt was carried out as follows. The geometric dimensions of the bolt, including the overall length, shank length, and threaded

length, were measured. The steel plates were designed with appropriate thicknesses so that, upon bolt installation, the requirements of NZS 3404 [1] regarding the number of threads under the loaded face of the nut were satisfied, at least 10 threads for M16×130 mm bolts.

The target bolt was initially tightened to the snug-tight condition using a standard wrench. Subsequently, a smart socket was installed on the target bolt, and the required rotation angle to achieve the fully tensioned condition in accordance with the part-turn method specified in NZS 3404 was marked. The rotation angle applied, using an electric torque multiplier, in this study was 270° [1].

Once the rotation angle reached 270°, the maximum tightening torque was recorded, and the nut was then further rotated until bolt failure occurred. The maximum torque at the point of bolt failure was also recorded.

4 Experimental Results

The experimental results were obtained from torque measurements recorded during the tightening of HSFG bolts using a smart socket device. The results focus on installation torque characteristics, including peak torque demand, torque variability, turn-of-nut variability and observed failure mechanism under different lubrication conditions.

4.1 Full Tensioning Stage

The relationship between tightening torque and bolt preload can be expressed using the classical nut factor equation $T = K F_p d$, where T is the applied torque, F_p is the preload, d is the shank diameter, and the nut factor K represents the combined effects of thread friction, bearing surface friction, and joint geometry [7,19]. More detailed formulations decompose the applied torque into thread and bearing friction components [7], while ISO 16047 [20] provides an experimental framework for directly measuring these contributions and deriving friction coefficients under controlled conditions. In this study, a detailed frictional decomposition was not pursued. Instead, an equivalent coefficient of friction was estimated to enable comparison between different lubrication conditions. The equivalent coefficient of friction was calculated using:

$$K_e = \frac{T}{F_p d} \quad (1)$$

T is the torque measured when the nut is rotated by 270° after completing snug-tightening. Bolt shank diameter, d , is 16 mm. F_p is taken as the minimum bolt tension to NZS 3404 [1]. K_e is termed as the equivalent coefficient of friction which is directly related to used only as an indicative parameter for comparison purposes. The reported equivalent friction coefficients represent mean values obtained from three specimens, with variability expressed using standard deviation (SD) and standard error (SE).

The results show that the equivalent coefficient of friction varies across different lubrication conditions, as illustrated in Figures 3, 4, and 5. However, due to the limitation of the assumption that the achieved preload is the same, these comparisons remain relative. Figure 3 indicates that site-applied lubrication results in the lowest equivalent

friction values, followed by GA 50, while higher values are observed for the as-supplied and unlubricated conditions.

Differences are also evident between lubrication locations, with nut-only lubrication resulting in lower equivalent friction values compared to thread-only lubrication. In addition, nut-only lubrication shows a smaller scatter in the calculated equivalent friction values (see Figures 4 and 5).

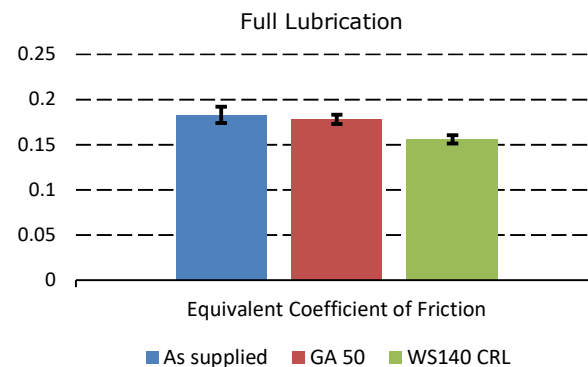


Figure 3 Variation in Equivalent Coefficient of Friction among Lubricants applied to both nut and thread.

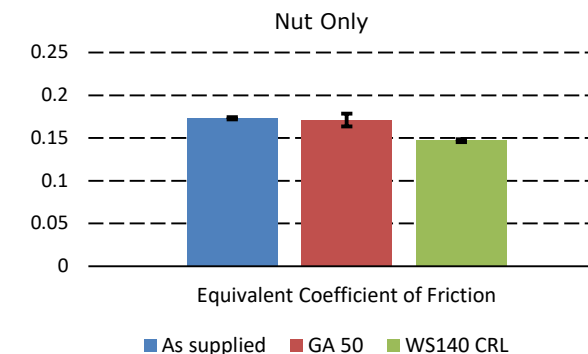


Figure 4 Variation in Equivalent Coefficient of Friction among Lubricants applied to Nut only.

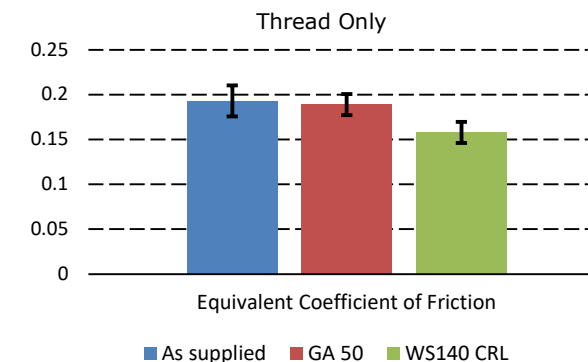


Figure 5 Variation in Equivalent Coefficient of Friction among Lubricants applied to Thread only.

4.2 Failure Stage

In the subsequent stage following the attainment of the full tensioning condition, the bolts were further tightened until failure occurred, as indicated by a sudden drop of the tightening torque to zero or by bolt fracture. At this stage, the final rotation angle was recorded, and the maximum

tightening torque was recorded.

It was assumed that the friction conditions remained constant throughout the tightening process. By applying the equivalent coefficient of friction, K_e , obtained from equation (1), the bolt failure load can be estimated using equation (2). The authors are well aware that this does not necessarily represent the preload at the failure, but is only an indicative parameter:

$$F_u = \frac{T}{K_e d} \quad (2)$$

Comparison with the theoretical tensile rupture capacity of an M16 bolt, 130 kN as the product of the tensile stress area, A_s , and the nominal tensile strength, f_u . This indicates that bolts with applied lubrication reached the expected failure load, whereas bolts retained in the as-supplied condition did not. This trend is also reflected in the observed failure modes. Bolts with additional lubrication predominantly exhibited tensile fracture of the shank with retained clamping, while bolts in the as-supplied condition showed evidence of thread plastic deformation and loss of clamping force.

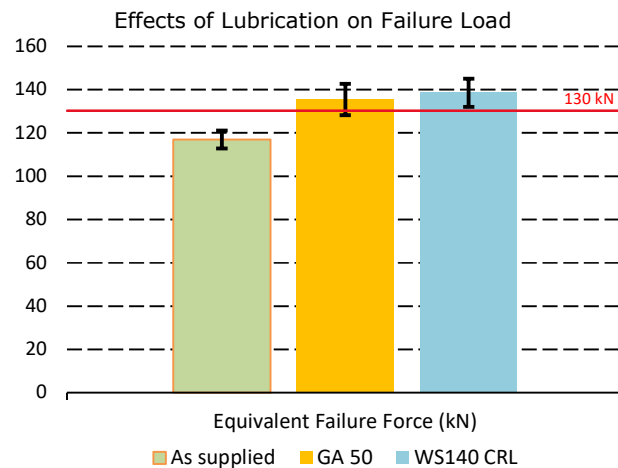


Figure 6 Variation in Equivalent Failure Load among Lubricants.

Friction conditions influence the distribution of tightening torque between thread friction, bearing friction, and the resulting tensile force in the bolt. Lower friction conditions (e.g. with lubrication) reduce resistance during tightening and may lead to higher tensile demand in the bolt under continued rotation, which can promote tensile fracture of the shank.

Conversely, conditions with higher coefficient of friction (e.g. as-supplied condition) result in greater energy dissipation during tightening, limiting the tensile demand and leading to more thread plastic deformation and loss of clamping behaviour.

The experimental observations support this interpretation, where lubricated bolts exhibited tensile fracture, while bolts in the as-supplied condition showed more thread plastic deformation characteristics.

In Figure 7, plastic deformation of the threaded part was

observed, and the nut could be easily loosened and removed by hand for bolts in as-supplied conditions.

As for bolts with GA 50, as shown in Figure 8, exhibited tensile fracture. However, in most cases the nut could be removed by hand, suggesting that excessive GA 50 lubrication may reduce nut resistance and promote loosening in some cases.



Figure 7 Failure modes of the group as-supplied lubricant.



Figure 8 Failure modes of the group GA 50 lubricant.

All bolts with WS140 CRL, see Figure 9, exhibited tensile fracture while all nuts remained tightly secured. None of the nuts could be removed by hand.



Figure 9 Failure modes of the group WS140 CRL lubricant.

5 Discussions, Recommendations, and Future Work

The experimental results show that lubrication influences the tightening behaviour of HSFG bolts installed using the part-turn method, including installation torque demand and the friction conditions. While the rotation-based procedure reduces sensitivity to torque scatter compared with torque-controlled tightening, lubrication still affects the installation torque demand, its variability, and the failure mechanism.

Site-applied lubricants consistently resulted in lower friction conditions and reduced torque scatter compared to as-supplied conditions. Nut only lubrication was observed to be more effective and stable than thread-only lubrication. Bolts tightened without additional lubrication showed higher friction variability and showed more plastic deformation of the thread after failure.

From a practical perspective, these findings highlight that lubrication should be treated as a controlled parameter rather than an incidental site practice. For applications using the part-turn method, a simple and consistent lubrication procedure preferably applied to nut only can improve tightening reliability without compromising constructability.

Future work will focus on:

- Direct measurement of bolt preload using load cells to establish a quantitative relationship between lubrication, installation torque, and achieved preload.
- Extension of testing to HSFG bolts of grade 10.9 to assess the influence of lubrication on higher-strength bolt assemblies.
- Investigation of preload retention and self-loosening behaviour under sustained and cyclic loading conditions.

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