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INFLUENCE OF THE STIFFNESS AND FRICTIONAL CHARACTERISTICS ON THE SHANK TORQUE OF SCREWS IN BOLTED JOINTS

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ABSTRACT

This work aims at determining the influence of tribological and stiffness characteristics of a bolted joint on the residual shank torque of the screw. Even if it is commonly accepted to consider such a residual torque equal to half the torque at the thread, the literature lacks experimental data about the topic. The residual shank torque combines with the axial preload and the external loads to bring about the overall stress on the screw. Hence, the higher the residual torque, the lower the admissible external load for given size and class of the screw. From there stems the need for an analytical tool allowing the designer to calculate the residual torque as a function of the key parameters of the joint.

Keywords: bolt**,** screw**,** shank torque, tribology.

INTRODUCTION

During tightening, the amount of torque given by the difference between the tightening torque, which is directly applied by the torque wrench, and the underhead torque, flows through the screw shank towards the threaded portion. This torque combines with the axial preload to bring about the overall stress state of the screw at tightening. Upon release of the torque wrench, a certain amount of the shank torque is released due to the elastic springback of the screw-plates system. In the literature, this phenomenon is just briefly treated by a few authors: they generally agree that approximately a half of the initial shank torque is released just a few seconds after torque wrench removal [Bickford, 2008]. This indication is given regardless of the frictional [Eccles, 2010] and stiffness [Alkatan, 2007] parameters, which govern the joint. The present contribution aims at assessing if there is any effect of the following parameters on the amount of shank torque being released after wrench removal: (i) the ratio between the torsional stiffness of the screw and of the plates, (ii) the friction coefficients in the underhead and in the thread. The experimentation has been run on a M20 8.8 class socket head screw, which has been instrumented by a double array of strain gauges, to simultaneously measure both the axial preload and the torque acting on its shank. Two different types of joined members have been examined: a cylindrical sleeve whose diameter is twice the screw diameter (compliant joint) and a rectangular plate whose transverse dimensions are more than ten times larger than the screw diameter (stiff joint). The underhead and thread friction coefficients have been controlled by properly selecting the lubrication conditions.

MATERIALS AND METHODS

The experimentation has been carried out on 8.8 class M20 socket head, black oxidized screws [EN ISO 4762: 2007], Figure 1. Each screw has been instrumented with three strain gauges (Vishay J2A-06-S033K-350), one placed along the screw axis (axial preload) and two angled by ±45° (shank torsion). The screws are coupled with M20 class 8, black oxidized, high nuts [EN ISO 4033:2012]. The screw underhead can mate with a black oxidized plain washer or directly with the aluminium plate or sleeve. In the case of slender joint, the screw is tightened to an EN AW 7075 T6, sleeve, which is in turn instrumented with both axial (Vishay J2A-06-S033K-350) and torsional (Vishay CEA-13-187UV-120) strain gauges. The tightening torque T is applied by means of a digital torque wrench (Gedore Torcotronic 2, 10-120Nm) fitted with a purposely designed torsiometer, which allows continuous sampling of the tightening torque. This signal is sampled with the same time-base of other signals, such as the axial preload and the screw shank torsion.

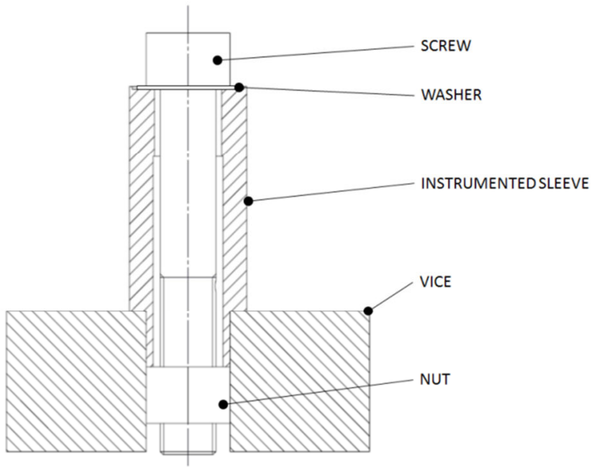

Fig. 1 - Cross section of the test apparatus

Three different lubrication conditions have been considered: (i) dry joint, treated by Loctite 7063 degreaser, (ii) Interflon Paste HT 1200, a multi-purpose ceramic paste, (iii) Polymer 400/00, a Lithium grease filled with PTFE particles. In the case of lubricated joint, three different scenarios have been evaluated: (a) underhead lubrication, (b) thread lubrication, (c) full lubrication (underhead and thread). Five consecutive retightenings have been performed under each lubrication condition. A target tightening torque of T=100Nm has been used throughout the experimentation. The following steps have been followed:

- The screw is tightened at the target torque T, while these signals are sampled: (i) tightening torque from torsiometer, (ii) thread torque (screw shank), (iii) screw axial preload, (iv) underhead torque (sleeve);
- The joint is allowed to rest for approximately [10-20] s;
- The screw is untightened

Figure 2 reports a typical curve obtained by sampling the aforementioned signals.

This procedure allows to fully determine the frictional response of the joint, based on its geometrical and elastic parameters [De Agostinis, 2016]: see Tab. 1 for the key parameters of the joint represented in Figure 1.

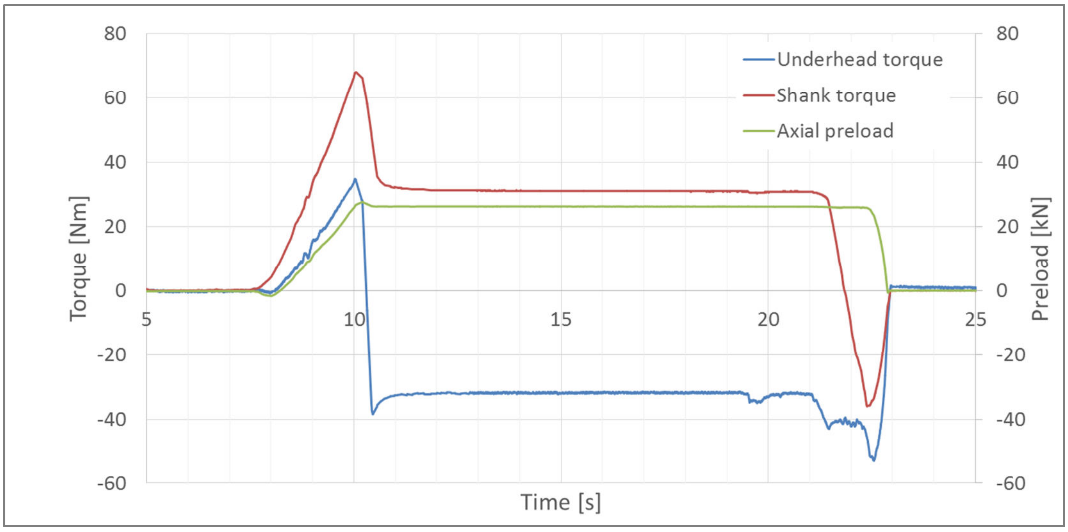

Fig. 2 - Tightening and untightening operations: axial preload, shank torque, underhead torque

Table 1 - Geometrical and elastic parameters of the test specimen

Name	Value	Unit
E_b	210,000	MPa
ν_b	0.3	-
G_b	80,769	MPa
d	20	mm
p	2.5	mm
d_2	18.38	mm
d_t	17.65	mm
d_k	30	mm
L_b	67	mm
d_w	23	mm
L_t	32	mm
D_{se}	42	mm
D_{si}	25	mm
L_s	79	mm
G_s	26,696	MPa

By looking at Figure 2, it can be seen how the tightening torque, the axial preload and the shank torque increase until tightening completion. After that, the screw axial preload and the thread torque undergo a decrease: the former by a very small amount while the latter by a bigger amount. The thread torque loss is quite well in agreement to one-half the peak value at tightening, as reported by the literature. At the same time, the sleeve torsion (underhead torque) shows a sign inversion: this occurrence is due to the elastic rebound of the components, which takes place upon removal of the torque wrench. The small decrease in terms of screw axial preload, which can be observed after tightening completion, is due to material setting in the underhead surface. Then, no significant decrease in terms of axial preload is noticed during the resting time: this time is too short for the materials to undergo any relaxation phenomena [Friedrich, 2014]. Moreover, no external load is applied to the joint, therefore self loosening is absent. When the release torque is applied, an inversion of the torque on the screw shank is immediately recorded, whereas the axial preload remains temporarily unaffected, until the "reversed" shank torque is high enough to unlock the threads. At this stage, the axial preload of the screw suddenly drops down to zero. Based on the observations described above, it is possible to set up an analytical model which allows calculating the residual shank torque after tightening, whose input parameters are the frictional and stiffness characteristics of the joint. Immediately after tightening completion, the following steps can be highlighted in the plot of Figure 2 and similar. These are:

- t_i: initial time, time at which the tightening operation ends, and the torsional relaxation begins;
- t_0: zero time, time at which the torque acting on the sleeve equals zero;
- t_1: peak time, time at which a negative torque peak on the sleeve (underhead) is achieved;
- t_f: final time, time at which static equilibrium has been reached by the joint. The modulus of the sleeve torque equals that of the shank torque.

At the initial time, both the screw shank and the sleeve are twisted clockwise due to tightening, even if by different amounts. These amounts can easily be calculated based on the torsional stiffnesses of the two parts, as exemplified by Eq. 1:

$$K_\theta = \frac{GJ_p}{L} \tag{1}$$

where G is the shear modulus, J_p the polar moment of inertia and L the torsional free length of the part. When the elastic rebound starts, the two parts start rotating counterclockwise, hence loosing part of their torsional preload, until t_0 when the sleeve torsional preload nullifies. Since this time on, the screw shank which still retains a certain torsional preload, starts dragging the sleeve towards negative torsion angles. Now, two cases shall be separated: (i) the screw and the sleeve keep rotating together until the modulus of the torque of the sleeve equals that of the screw shank (equilibrium condition), (ii) the screw and the sleeve rotate together until the sleeve torque equals the maximum torque which is frictionally transmissible via the underhead surface. When this limit is overcome, the screw starts sliding and the shank torque keeps dropping until it equals the transmissible torque. Based on the frictional parameters of the joint, the analytical model is able to establish which condition applies and to calculate the residual shank torque (at equilibrium) accordingly.

RESULTS AND CONCLUSIONS

Table 2 summarizes the outcome of the experimentation, along with a comparison between the experimental results and the analytically calculated residual shank torque. Experimental values of the residual shank torque lie between 41% and 58%, which is quite close to the rule of thumb of 50% suggested by the literature, even if a noticeable scattering of the results is observed.

Table 2 - Residual shank torque calculation under different tribological conditions

		Underhead	Thread	Underhead	Thread	Underhead	Thread	Underhead	Thread	Underhead	Thread	Underhead	Thread
	Lubrication	Ceramic paste	Dry	Ceramic paste	Ceramic paste	PTFE grease	PTFE grease	Dry	Dry	Dry	PTFE grease	Sand blasted	PTFE grease
	Friction coeff.	μ_b=0,10	μ_{th}=0,22	μ_b=0,09	μ_{th}=0,19	μ_b=0,10	μ_{th}=0,10	μ_b=0,13	μ_{th}=0,32	μ_b=0,11	μ_{th}=0,11	μ_b=0,31	μ_{th}=0,13
Res. shank torque	**Experimental**	41%		44%		57%		41%		58%		50%	
	Analytical	40%		44%		79%		41%		76%		63%	
	Sliding	**YES**		**YES**		**NO**		**YES**		**NO**		**NO**	
	Error	**-1%**		**0%**		**22%**		**0%**		**18%**		**13%**	

The analytical model well predicts the residual shank torque in the case of underhead friction coefficient lower than that at the thread (e=1%). Greater errors (e=22%) are found when the friction coefficient at the underhead becomes comparatively higher. Future developments of the present work will include the completion of the testing plan on a stiffer (plate-like) joint geometry and the extension of the analytical model to this case. Moreover, in order to investigate the less accurate response of the analytical model in the case of sticking, numerical FE models have been prepared, in order to better understand the relative motion between head and underhead surface, and between the threaded portion of the screw and of the nut.

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