COB-2021-0653
ANALYSIS OF THE TORQUE BEHAVIOR VS CLAMP FORCE WITH DIFFERENT SURFACE TREATMENTS IN M8 SCREW

Rodrigo Sperandio Kaiser
Giuliana Sardi Venter
Universidade Federal do Paraná, Av. Cel. Francisco H. dos Santos, 210 - Curitiba - PR, 81130-001
rodrigoskaiser@gmail.com
giuliana.venter@ufpr.br

Abstract. *The equation that relates torque to the clamping force is linear and has the K factor among the variables, which determines the slope of this line when plotted on a graph. There is more than one factor that determine the K factor of the joint, such as the hardness and roughness of the parts, lubrication of the constraint, dimensional tolerance of the thread, and the surface treatment of the parts. The aim of the study is to analyze the surface treatment of the M8 screw bolt joint parts in the torque vs. clamping force ratio. To obtain the results, the hardness of each sample with surface treatment was collected with a Brinell machine, and a bench of experiments was designed to collect the clamping force from the applied torque for each surface treatment. As a result of the study, a graph indicating the best line of each surface treatment was constructed and were also obtained the values of the factor K of the chrome surface treatment, k = 0.190, and untreated part, k = 0.100.*

Keywords: *Surface treatment, Screw joint, torque, clamping force ratio, K factor.*

1. INTRODUCTION

Any manufactured equipment has the need to somehow unite the parts, and the range of ways to joint parts is wide, from permanent to non-permanent unions. Within the category of fasteners that do not damage when assembled or removed, the screw is the most used fastener. It is rare to find equipment that does not have a part fixed by screws. As the application of screws is vast, there are many studies in order to know and narrow down the intrinsic variables of the assembly process, in order to avoid future quality problems, minimize costs and improve product properties (Quadros, 2018).

An industry in which bolts and screws are used daily in abundance is the automobile manufacturers. Due to the versatility and time saved, it is mostly used torquemeter and nutrunners to access the torque during assembly, in order to reach the necessary clamp force in the bolted joint (Norton, 2013). As there are several assemblies using screws, to dimension and control all torques is almost impossible, it is dimensioned by product development engineering and only critical or essential torques are controlled by manufacturing. For other assemblies are used generic torques dimensioned to screw thread diameter and screw class. In a survey carried out by Bickford (2008), it was shown that there are around 40 variables present in the joint bolted when the fastener is being torqued, and one of them, the most important during the assembly process, is the bolt preload, because this variable determines that there will be no failure, in a bolted assembly, both during in clamp and a work operation (Bickford, 2008)

Seeing that not all torques are controlled in a manufacturing area and that generic torques are used to apply clamp force in rigid bolted join independently of the surface conditions, the study of the influence of the surface treatment in rigid bolted joints on the torque vs clamp force relationship aims to analyze if there will be a difference in the clamp force of joints with different surface treatments with the application of a same torque for all samples.

2. METHODOLOGY

2.1 Mathematical equations

The types of fasteners are divided into 2 major groups, permanent fasteners and non-permanent fasteners. Inside the non-permanent fasteners, which are those that do not damage the joined parts in case of removal from the fasteners, are screws and nuts (Quadros, 2018). Bolted joints, the name given to parts fixed by screws, usually have the elements represented in Figure 1, and aim to obtain a robust and stable fixation through the tensile force applied to the screw (Bickford, 2008).

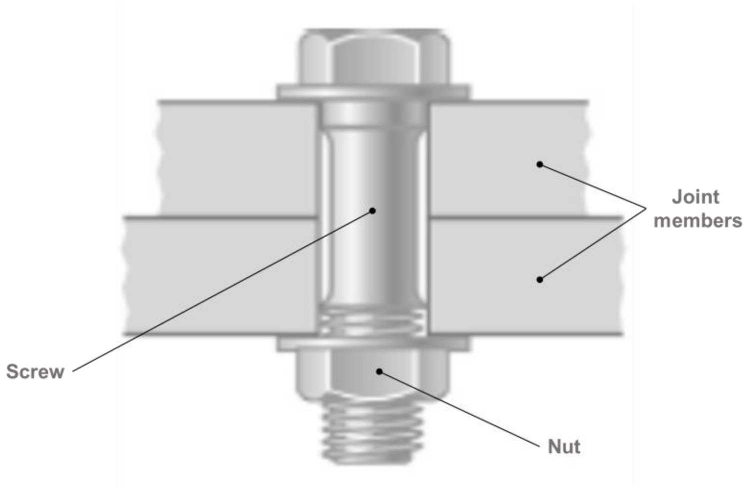

Figure 1. Simplified bolted joint (Adapted from Collins, Busby and Staab, 2019)

The torque applied to the bolt results in a preload force in the joint. Consequently, the joint strength has the same intensity as the preload force. In the absence of external load, it is possible to say that the preload is equal to the joint strength, and if there is no external load, it is possible to say that the preload screw is equal to joint strength, as shown in Figure 2 (Budynas; Nisbett, 2016).

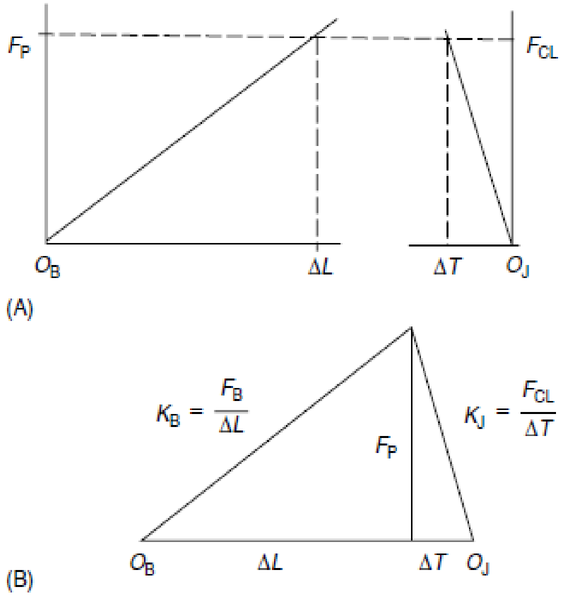

Figure 2. Screw stiffness and joint stiffness (Bickford, 2008)

In the face of several methods of applying a clamp force to a bolted joint using a torque, which is applied with a torquimeter or a nutrunner for controlling the torque, is the most used form due to its low cost and ease of application. The relating torque to clamp force is described in Eq. 1. The variable K, known as the torque coefficient which is responsible for the relating the torque to the preload force on the screw, summarizes many variables into a single constant such as: friction, torsion, bending, plastic deformation of the threads, and with that, makes this value easier to be found in experiments to analyze the behavior of the joint (Bickford, 2008).

$$\frac{T}{F_P} = K.d \tag{1}$$

Being:
T = torque applied to the bolt (Nm)
FP = preload on screw (N)
d = nominal screw diameter (mm)
K = torque coefficient (dimensionless)

Other way to describe the relationship between torque and preload on screw is shown in Eq. 2, which uses the friction coefficient to and some screws dimensions variables (Bickford, 2008).

$$T = F_P\left(\frac{P}{2\pi} + \frac{\mu_{th} r_{th}}{\cos\beta} + \mu_s r_s\right) \tag{2}$$

Being:
T = Torque applied to the bolt (Nm).
FP = Preload on screw (N).
P = Thread pitch.
µth = Friction coefficient in the thread of the nut with the screw.
rth = Effective contact radius of the thread (mm).
β = Half of the thread angle (30° for metric thread).
µs = Friction coefficient between nut and gasket surface.
rs = Effective contact radius between nut and contact surface (mm).

Each term in Eq. (2) represents a physical phenomenon during screw tightening.

The term $F_P\left(\frac{P}{2\pi}\right)$ is produced by the action of the thread nut inclined plane on the screw thread. It can be called the bolt strength component, and it is responsible for compressing the joint by torquing the bolt body. The term $F_P\left(\frac{\mu_{th} r_{th}}{\cos\beta}\right)$ is produced by friction between the nut thread and the bolt, and also contributes to torque the bolt. The term $F_P(\mu_s r_s)$ is the reaction torque created by the friction between the nut face and the joint (Bickford, 2008).

2.2 Experimental procedure

The aim of this study refers to the analysis of the bolted joint base parts surface treatment influence in the relationship of torque vs joint clamp force, that is, to quantify the K factor of the joint. The same bolt and nut pattern will be maintained, changing only the surface treatment of the joint seating parts in each test. To obtain the necessary data a test bench will be designed.

In order to obtain the K value of the joint, the ISO 16047 standard requires equipment that quantifies the joint torque and clamp force simultaneously. To collect the clamp force, a ring load cell brand HBM with a load capacity of 40 kN (HBM, 2020) was used, and a digital torquemeter with a range from 0 to 60 N.m was selected. The base material was manufactured using a flat bar 1.1/2" wide and 3/16" thick, and as a final product parts followed the dimensions shown in Figure 3.

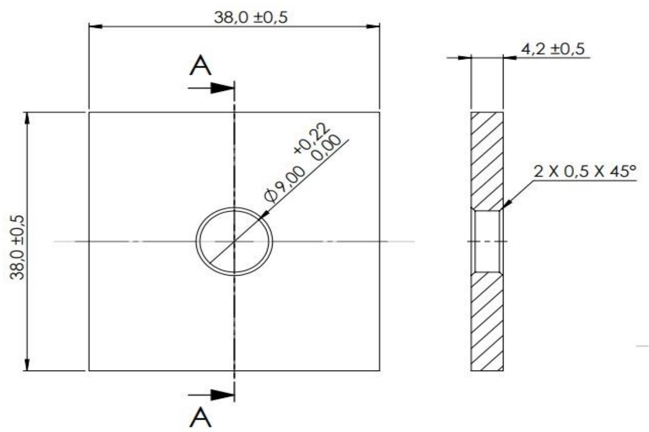

Figure 3. Dimensions of base part

The surface treatments applied to the base part were hard chrome, nickel and zinc. In order to have a baseline, there were parts with no surface treatment, as well, in the experiments. Figure 4 indicates the range of treatment being tested.

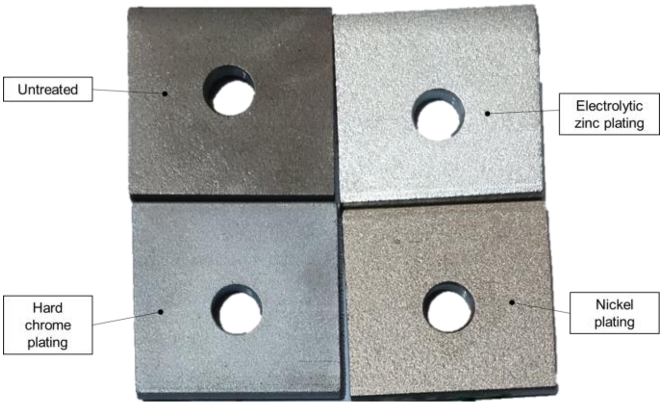

Figure 4. Appearance of each surface treatment

The selected screw was the hexagonal screw with ISO 15071 flange – M8x35 – 8.8, and nut that complements the screw. The surface treatment of the screw and nut selected is black nickel zinc electroplating with the addition of an organo-mineral finish known as FINIGARD 105. The µG of the screw is 0.17 and the screw K coefficient found in the DDT test performed by screw supplier is 0.25.

In addition to collecting torque vs clamp force, the hardness and roughness of the base part were collected both before and after the torque test, in order to have more variables to understand the influence of the surface treatment of the base part on the torque coefficient. Through the ALBERT GNEHM durometer, the hardness of 5 pieces of each sample was collected. The results can be seen in Table 1.

Table 1. Hardness of each surface treatment

Brinell (hb)	1	2	3	4	5	Average	Deviation
Hard Chrome	187	187	187	180	187	185,6	3,1
Nickel	170	170	170	170	177	171,4	3,1
Untreated	170	177	170	170	170	171,4	3,1
Zinc	156	158	158	161	156	157,8	2,0

The hardness values found in Table 1 highlighted that the hard chrome surface treatment stood out among the other treatments due to the higher value found, while the zinc coating treatment showed that the hardness had a decrease greater than 10 Brinell in relation to the untreated part. The samples with nickel treatment showed no difference between the raw part in hardness, keeping both an average of 171,4 Hb

For roughness collection, the Mahr S2 rugosimeter, was used. For data collection, a cut-off of 0.8 x 5 mm was used, in which the first and last results were disregarded. To obtain a comparison value of before and after clamp, the roughness was collected in a region close to the joint clamp area, and after the torque vs force experiment, the roughness was collected in the area where the screw clashed with the part during torque as can be seen in Figure 5 and the results can be seen in Table 2.

Figure 5. Roughness collection after torque test

Table 2. Average surface roughness of each type of sample

	Before		After	
Samples	**Ra (μm)**	**Rz (μm)**	**Ra (μm)**	**Rz (μm)**
Nickel	2,99	16,48	3,09	15,16
Hard Chrome	3,51	20,20	3,61	19,47
Zinc	2,68	14,46	2,20	11,21
Untreated	3,54	18,46	3,00	15,16

Table 2 shows the mean values of roughness before tightening and values after tightening for each type of treatment. Analyzing the Rz data, it is highlighted that in all surface treatments there were lower values of Rz after application of the torque test vs. clamping force. For samples without treatment and zinc plating, the Rz values dropped close to 3 points, and for hard chromium and nickel there was a slight decrease close to 1 unit of difference. Taking untreated parts as a basis for comparison, we see in Table 2 that the surface roughness of nickel and zinc surface treatments are lower, while the hard chrome increases the roughness.

The test bench with all the necessary equipment and listed in the project is represented in Figure 6. For the experiment, 10 parts of each sample were used in which 2 parts of the same surface treatment formed the base parts of the bolt joint as shown in Figure 7. With that it was possible to collect 5 results for each surface treatment.

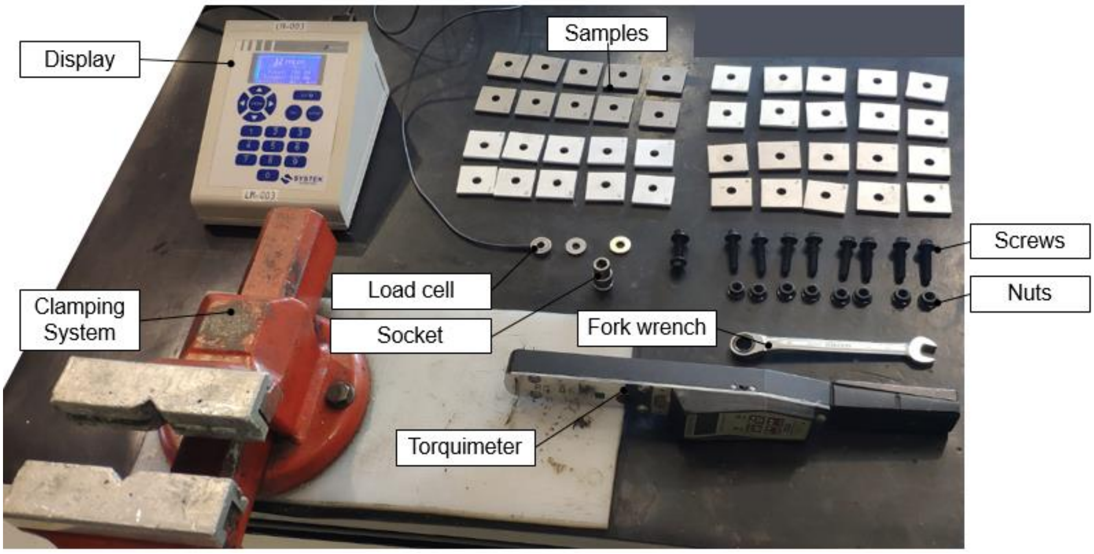

Figure 6. Test bench

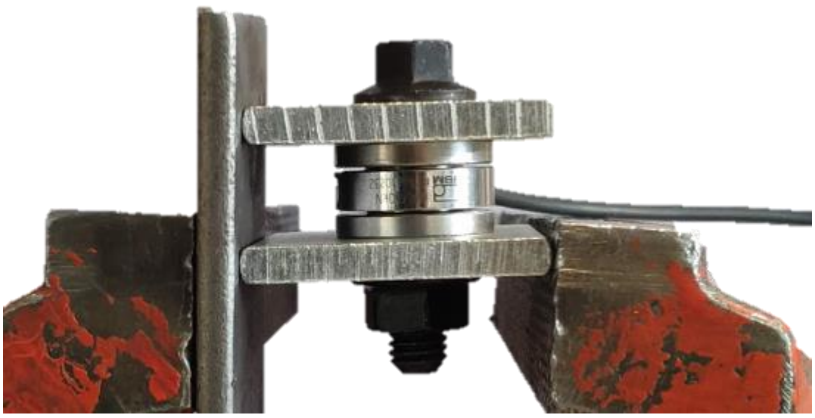

Figure 7. Bolt joint for data collection

3. RESULTS AND DISCUSSION

The method used to collect the results was to apply a known torque and collect the joint clamp force soon after. The torque values applied for the collection are shown in Table 3. With the 5 clamping force values collected for each specified torque, it was possible to draw up the graph represented in Figure 8 with the average of the points found and form the line that best represents the data collected for each surface treatment.

Table 3. Selected torques for clamp force collections

Torque (N.m)	5	10	15	20	25	30	35	40	45	50	55

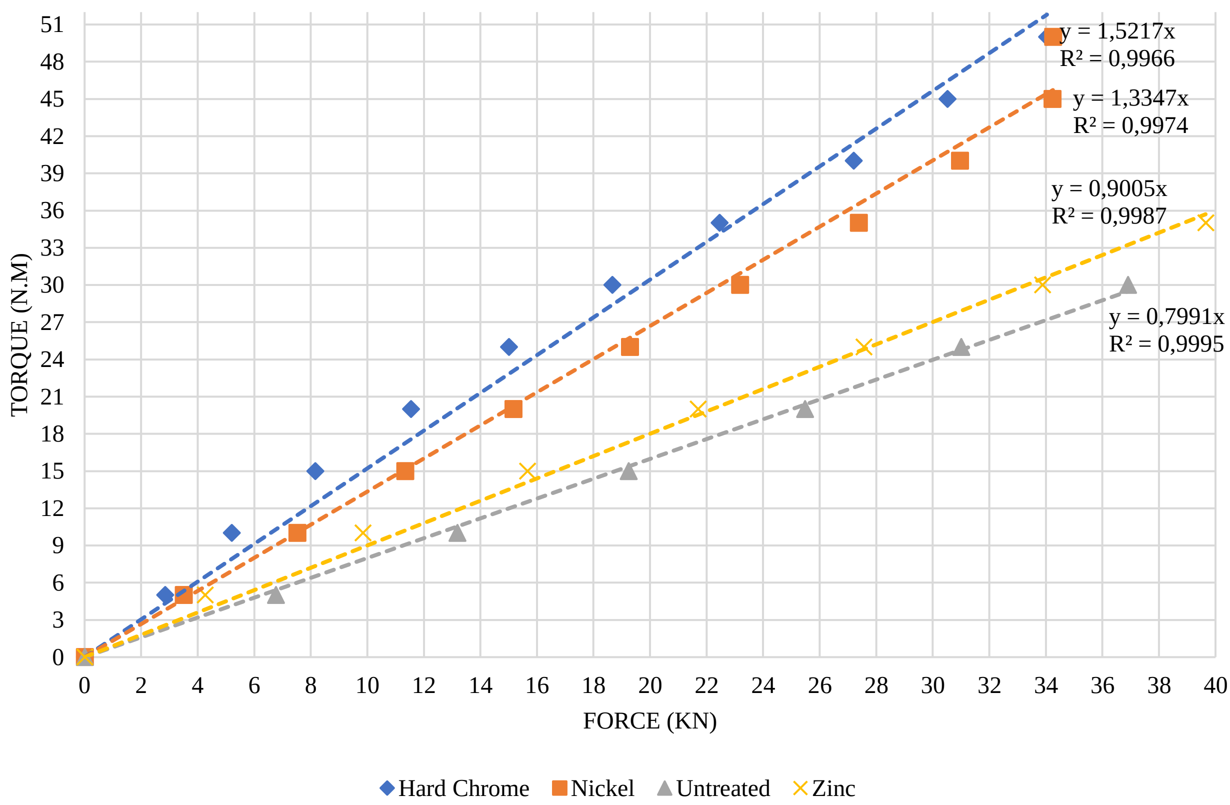

Figure 8. Torque vs clamp force ratio of each surface treatment

Using Eq. 1 and the angular coefficient of each straight line in Figure 8, it is possible, by dividing the angular coefficient by diameter of the experiment screw, to determine the K value of each bolted joint. The results are shown in table 4.

Table 4. K factor for each superficial treatment

Superficial treatment	Angular coefficient	K factor
Untreated	0,799	0,100
Eletrolitic zinc	0,901	0,113
Nickel	1,335	0,167
Hard Chrome	1,522	0,190

4. CONCLUSION

From the results, it is clear that the surface treatment of the base part in a bolted joint has a great influence on the torque vs. clamp force behavior. Just by changing the surface treatment of the base part, the torque coefficient differs from each other leading to extremely high torque values to achieve the same clamping force as other surface treatments. Comparing the untreated surface with the chromed surface, there are torque values in which the clamp force is nearly double one in relation to the other, as for example at 25 N.m.

Seeing the other variables presented, it is noted that it is not possible to arrive at a strong correlation between the roughness, hardness and clamp force variables, because as much as there is a similarity of a variable in a pair of surface treatments, for other variables, these pairs of surface treatments are completely out of step with each other. Recalling Eq. 1 in which the torque coefficient relates the clamp force to torque, the "K" of the equation holds within itself many variables that make each bolted joint have its own characteristic. Influencing factors such as surface finish of the base part, hardness, roughness, chemical affinity, lubricants, speed, among others, change the coefficient of friction of the set, which consequently change the K factor. With the change in the surface treatment of the base part, it is noted by the results that this single physical change in the bolted assembly simultaneously alters several important parameters, such as hardness and roughness, and this makes each bolted joint with its respective surface treatment on the base part at the same time have a unique torque coefficient.

5. REFERENCES

Bickford, J.H., 2008. *An Introduction to the Design and Behavior of Bolted Joints*. Editora CRC Press, New York.

Budynas, R.G.; NISBETT, K., 2016. *Elementos de Máquinas Shigley*. Editora AMGH, São Paulo.

Collins, J.A.; Busby, H.R.; Staab, G.H., 2019. *Projeto Mecânico de Elementos de Máquinas: Uma Perspectiva de Prevenção da Falha*. Editora LTC, Rio de Janeiro.

HBM. *Mounting Instructions: Force washer KMR*. 5 Out. 2020. https://www.hbm.com/fileadmin/mediapool/hbmdoc/technical/A02114.pdf

ISO 15071:2011. "Hexagon bolts with flange — Small series — Product grade A". *International Organization for Standardization*. Genebra: ISO; 2005.

ISO 16047:2005. "Fasteners -Torque/clamp force testing". *International Organization for Standardization*. Genebra: ISO; 2005.

Quadros, M.L., 2018. *Elementos de Máquinas*. Editora SAGAH, Porto Alegre.

Norton, R.L., 2011. *Projeto de máquinas: uma abordagem integrada*. Editora Bookman, Porto Alegre.

6. RESPONSIBILITY NOTICE