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COMPARATIVE STUDY OF THE TENSILE STRENGTH OF INTERNAL THREADS VERSUS THE USE OF FALSE THREADS (HELICOIL) IN ALUMINUM ALLOY

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Abstract. How difficult it is to design a set without using threaded elements. Therefore, the bolt is the most used fastening element for detachable joints and, with technological advances, the use of increasingly resistant materials, provide dimensional reduction. However, only high-sustainability threads achieve high-strength joints. Failures, called Thread Stripping, similar to thread stripping, which occur in materials such as aluminum, arising from the axial force generated by the bolt when exceeding the maximum resistance of the thread threads, are catastrophic. A possible solution would be the application of false threads, commonly known as helicoil. For this article, a 3003 aluminum plate was used, due to the ease of acquisition and because they are more economical materials. Evidently aluminum, when we talk about threads, does not have a very high tensile strength. Composing the studies, we used helicoil that are very resistant to pulling out. The objective was to investigate and compare the tensile strength of threads produced by machining versus thread by insertion. The results showed that when we insert the false threads, the material supports a torque approximately 50% higher, causing fracture by simple traction of the bolt.

Keywords: *Aluminum Alloy, False threads, Internal threads, Helicoil*

1. INTRODUCTION

The presence of bolted unions in the most diverse segments is due to the low unit cost and the ease of assembly and disassembly of the parts, that is, bolted unions allow the components of the set to be separated without damage to the parts that were joined. Other fastening elements, such as rivets and welds, do not allow this maneuver. In addition, bolts can be used as fasteners to join parts of any nature. On the other hand, bolts cause non-uniform stress distribution in the connected parts, that is, they act as stress concentrators. This fact must be considered during the design (Shigley, 2005).

Failures due to ductile fracture in fasteners are worrying factors in the metalworking industry. Factors such as material properties, design geometry, friction, preload, stresses, among others, must be well studied. However, the more complex aspects must be considered for calculating the strength of the bolted joint. As an example, the influence of the length of the bolt, on the limit of resistance to fatigue, the distribution of tensions in the bolt and in the nut.

The stresses applied to the bolt are caused by the preload of the bolt and by external stresses applied to the bolted-together parts. To support all this loading, the choice of the bolt with appropriate dimensions is of paramount importance to avoid undue or early failure of the union (Crocillo, 2012). Aluminum alloys are widely used in the naval, aeronautical, automotive, orthotics, prosthetics, wheelchairs and in general in the metalworking industry, due to their numerous advantages, such as low density, high strength, and good resistance to corrosion. However, when used as part of bolted joints, these elements end up being oversized to resist efforts in the thread regions. This is because they are susceptible to fracture due to the application of torque.

According to Brazilian Aluminum Association – ABAL, the tensile strength limit for pure annealed aluminum is approximately 48 MPa (4.9 kg/mm²). The value increases depending on the alloy, cold work and heat treatment (when possible). As for the flow limit, it is 0,2% of the original length measured in a normal specimen. The limit for pure aluminum is approximately 12.7 MPa (1.3 kg/mm²). The modulus of elasticity of aluminum is 7030 kg/mm². Figure 1 shows the typical deformation curves for aluminum alloys.

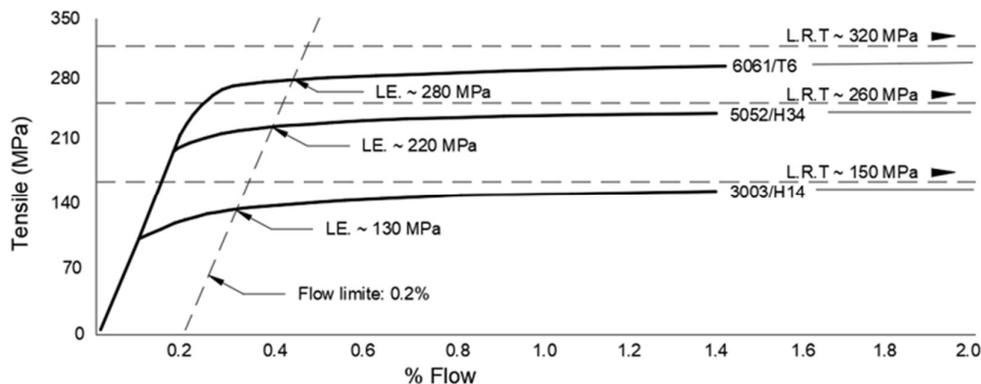


Figure 1 - Typical deformation curves for aluminum alloys.

1.1 Strength Rating of a bolt

According to the classification of bolts (ISO 898-1), the symbol for property classes of bolts consists of two numbers, separated by a dot. The number to the left of the dot consists of one or two digits and indicates 1/100 of the nominal traction. The number to the right of the dot indicates 10 times the ratio between the rated yield strength and the rated tensile strength. The standard indicates the characteristics of the manufacturing material and the specific heat treatment for each class. Thus, the bolts involved in classes 4.6, 4.8, 5.6, 5.8 and 6.8 are composed of carbon steel or carbon steel with additives and do not require heat treatment. For grades 8.8, 9.8 and 10.9, we have carbon steel with additives (e.g. B, Mn or Cr) quenched and tempered, or alloy steel quenched and tempered (Figure 2). For bolts in class 12.9, quenched and tempered alloy steel, or even carbon steel with additives (e.g. B or Mn, Cr or Mo) quenched and tempered.

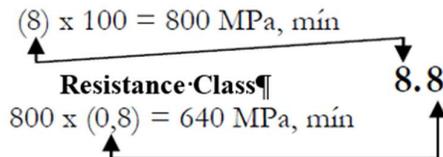


Figure 2 - Understanding the terminology of bolt strength classes.

When bolts are overtightened, they can suffer deformations in the threads, can elongate and even fracture. To prevent this from happening, tightening torque values are defined, considering the gauge and resistance class of the products (Garcia, 2011). Then, knowing the resistance class of a bolt and using its geometric factors, it is possible to calculate the force generation capacity that can be obtained from it. Remembering that the bolt will start the deformation at the yield point and not at the tensile limit. Furthermore, the values refer to the axial force (pure traction). In a tightening process, we have a combined effort, as axial and torsional efforts occur simultaneously. We can graphically represent the different regions of forces obtained from a bolt, considering its degree of deformation. (Garcia, 2011).

Croccolo et al. propose an Eq. (1) to relate the axial preload (F_i) imposed on the bolt with the tightening torque (T) applied. This relationship is defined in the equation below, where (p) is the bolt pitch, (μ_t) the bolt thread friction coefficient, (d_2) the average bolt diameter, (μ_h) the friction coefficient under the bolt head. Bolt and (D_{mu}) the average collar diameter.

$$T = F_i (0.159 p + 0.577 \mu_t d_2 + 0.5 \mu_h D_{mu}) \quad (1)$$

The tightening process is directly related to the efficiency of the bolted joint. According to Cioto (2001), the tightening method influences the necessary sizing of the bolt because, in addition to the axial force, the bolt absorbs torque (torque moment). The greatest influence, however, is that which comes from the variation in pre-stress (pre-load) in the case of different bolting methods. Shear failure in a bolt may involve stripping of threads in both the nut and bolt. This will depend on the strength of the nut and bolt materials, whichever is weaker will have its threads torn (Norton, 2013). So, we have that for bolts, the area under shear or tear A_s for a thread is the area of the cylinder of its smallest diameter d_r is given by the following Eq. (2):

$$As = \pi \cdot dr \cdot Wi \cdot p \quad (2)$$

The area for one thread pitch obtained from this equation can be multiplied by all, one or some fraction of the total number of engaged threads. In the case of female threads or nuts, tearing occurs in their largest diameter, and the area under shear for a thread is given by Eq. (3):

$$As = \pi \cdot d \cdot Wo \cdot p \quad (3)$$

Where p is the thread pitch, Wi is the factor that defines the percentage of the pitch occupied by the metal in the smaller diameter of the bolt and Wo is the factor that defines the percentage of the pitch occupied by the metal in the larger diameter of the nut (Eq.(4)). For metric thread, the area factors for thread cutting shear are $Wi = 0.80$ and $Wo = 0.88$.

$$\tau_s = F/As \quad (4)$$

In the case of the area of the bolt that undergoes traction, the average of the smaller and primitive diameters is considered, according to Eq. (5). A fixing bolt normally suffers only axial tension load.

$$At = \frac{\pi}{4} \left(\frac{dp + dr}{2} \right)^2 \quad (5)$$

In a bolt that is being stressed by an external tensile axial load and has no initial preload, the stress in the bolt can be calculated by Eq. (6).

$$\sigma_t = Fe/At \quad (6)$$

Considering At = area under tension, Fe = Force applied to the bolt.

Now, when a nut is twisted to preload, a torsional load is applied to the bolt through its threads and vice versa. If the friction on the threads is high, the twist in the bolt can be appreciable. This is the main reason for using thread lubrication prior to bolt assembly. If there was no friction in the threads, the torsional load on the bolt would be close to zero (Norton, 2013). A torsional stress is generated in the bolt body during tightening, as defined by Eq. (7).

$$\tau = \frac{Tr}{J} = \frac{16Tf}{\pi(dr)^3} \quad (7)$$

Where Tf = total torque force and dr = root (smallest) diameter of the thread. This torsional stress combines with the tensile stress in the bolt to create a principal stress greater than the initial tensile stress. When torsional stress is relieved or disappears, principal stress will be reduced.

Having seen that a high preload is very desirable in important bolted connections, we must consider ways to ensure that this preload is developed when the parts are assembled (Shigley; Mischke; Budynas, 2005). Preload is achieved when the bolt is elongated by a sufficient amount, however it is very difficult to measure the elongation that the bolt undergoes. So, to ensure the preload, torque control is performed during bolt tightening, normally using a torquemeter. According to Norton (2013) according to the results of Brake, Kurtz (1965) the torque (T) can be related to the preload according to Eq. (8). Where K = coefficient of torque (for the studies we used $k = 0.2$), Fi = Preload and d = external diameter of the bolt.

$$T = K \cdot Fi \cdot d \quad (8)$$

The coefficient of torque is related to the coefficient of friction, which depends on the surface hardness, precision and degree of lubrication. On average, the coefficient of friction with an approximate value of 0.15 is adopted. Other factors that can be computed to define the torque coefficient are whether the threads are thick or thin (Abrão; Pertence; De Lima, 2011). According to Nascimento (2003), bolt joints must be dimensioned considering the maximum external loads they suffer and the tensile strength necessary for the bolt to be able to withstand external loads without causing slippage between the parts of the joint. Typically, bolted joints will be undergoing tensile or shear stresses, or a combination of both loads. There are specific calculations for each situation and type of loading.

When the two wires are joined, a shear stress is applied along the threaded section. If this voltage becomes too high, the section will be cut. This is known as internal thread stripping or Thread Stripping. Thread stripping is a complex phenomenon that occurs in a threaded joint under tensile load. Normally, this pullout occurs when the pressure area on the threads is not sufficiently superior, generating a tension greater than the resistance of the material. The thread removal

mechanism is complex and involves thread bending (which occurs under high loads) and nut dilation (which results in shear plane movement).

1.2 Insert Threads – Helicoil

Helicoil is a system widely used in the technology of fixing parts and/or components (bicycles, injection pumps, engines, among others). In their unique appearance, they resemble "traction springs", or even the threads of a bolt, but without its central cylinder. Roughly speaking, they are helical thread fillets (with a triangular profile) sized to obtain self-fixation in the installation, where glue or another type of chemical lock is not necessary. The helicoil, also known as "dummy threads" or "threaded inserts", can be found in both millimeters and inches, with length variations depending on the manufacturer. As for installation, it is relatively easy, as long as you have the right tools. In general, they are elements with an extraordinary cost-benefit ratio, with features and technical quality superior to a conventional bolt.

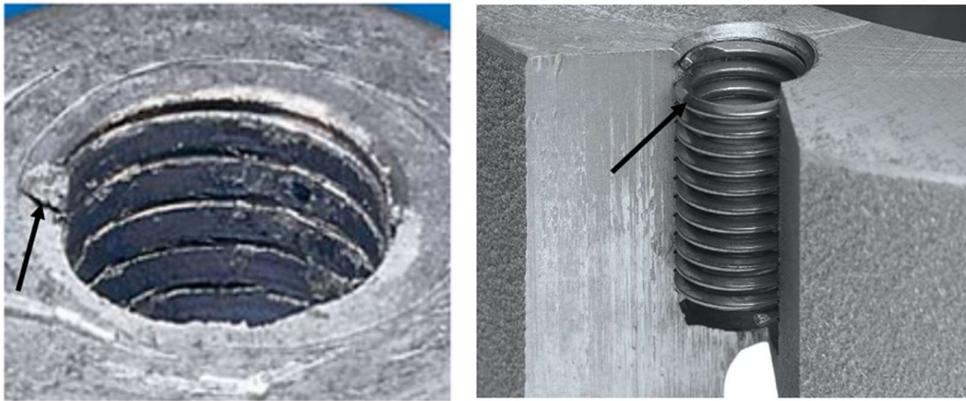


Figure 3 – Damaged female thread / Helicoil inserted into an aluminum part.

The helicoil, allow the threads, whether the threads are new or damaged due to the tightening process (Figure 3). This process is carried out when using ductile materials such as aluminum, aluminum alloys, magnesium, or hard plastics. According to the manufacturer Bollhoff, the function of the helicoil is to produce structural reinforcement in materials of low mechanical resistance, with very high precision thread fillets. They are usually made of austenitic stainless steel, with a hardness of 425 Hv 0.2 (min), and tensile strength (σ) = 1400 N/mm², with a reduced coefficient of friction, which provides an increase in bond strength. The high elasticity of the insert favors a regular distribution of loads and stress and allows for optimal contact between the bolt and the insert. In this way, a better distribution of loads is obtained from the bolt to the thread. The efficiency of the bolt increases, whether for static or dynamic loading.

2. METHODOLOGY

The purpose of this article was to develop a test bench, using easily accessible materials, common on the market, that represented the daily life of industrial workshops. To this end, no machining technology that required CNC machine tools was used. The focus is to show that with simple machining and common resources, we can redo a damaged thread, without any functional loss of the mechanism or equipment, thus providing, in many cases, an easy and functional technical action. This activity will cover materials such as steel, aluminum, some composites, and other materials. In the development of this work, 3003 aluminum specimens were used, regularly used in general mechanical construction projects, with the technical specifications described in Table 1.

The choice of resources announced in this work is associated with the proposal to carry out a representative test, but one that can be easily reproduced by a small company. In order to optimize testing costs, as well as meet the minimum dimensions found in suppliers in the region. Even though we are aware that, for an M10 x 1.5 screw, a # 3/8" plate would not be recommended due to the thickness being less than the screw's nominal diameter, we believe that for demonstration purposes, the tests would be functional.

Limits of Chemical Composition (%)									
Silicon	Iron	Cooper	Manganese	Magnesium	Chrome	Zinc	Titanium	others	Aluminum
0.6	0.7	0.05 - 0.2	1.0 - 1.5	---	---	0.1	---	0.15	Restante
Mechanical Properties of Aluminum - 3003									
Resistance Traction Minimum (MPa)	Resistance Traction Maximum (MPa)		Flow (MPa)	Stretching Minimum (MPa)	Toughness (HB)				
150	---		130	---	50				
Thermal insulation, bus bodies and vans. Vehicle Identification Plates, boats for navigation, Silos, Household items, tanks for industry, Fire extinguishers, Cans for beverages and food, tiles, gutters, linings.									

Table 1 - Chemical Composition Limits and Mechanical Properties of Aluminum 3003

The CAD models helped in making decisions regarding the distance between the holes, position of the fastening elements and subsequent assembly of the hexagonal socket. Therefore, the geometric and dimensional definitions of the specimens follow according to the drawing shown in Figure 4. The plates are 3/8" (9.525mm) thick, measuring 80 mm x 2. 1/2" (63.5 mm), arranged with 4 threaded through holes M10x1.5, machined using the 3-stage tapping kit.

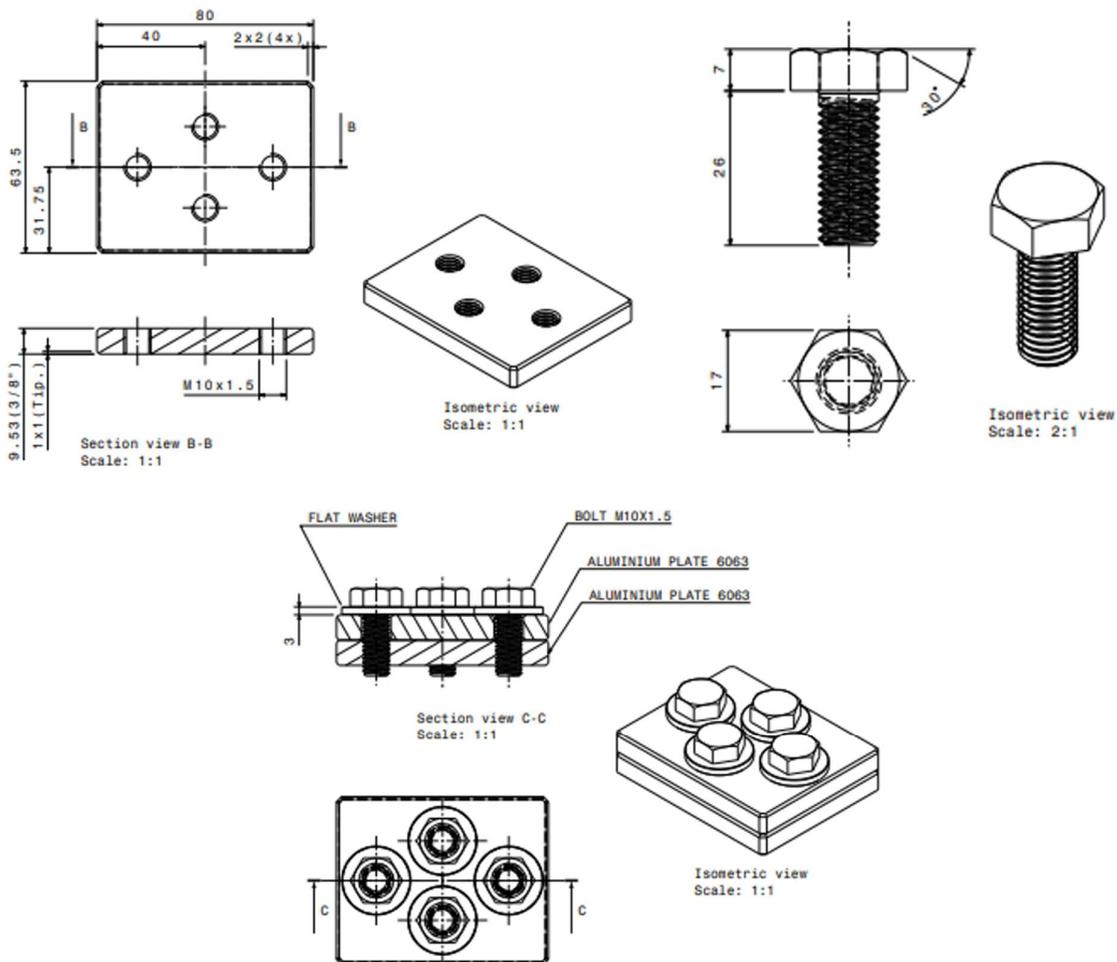


Figure 4 – The 2D drawing of the aluminum plates used in the test.

The positioning arrangement of the holes aims to meet a minimum design spacing for the side surfaces and provide a greater number of samples, as well as allowing access to the 17 mm hex socket. The counter piece has the same specifications but has through holes. Table 2 shows the elements that make up each set to be tested.

Item	Description	Qty.
01	Bolt M10 x 1.5	4
02	Flat washer M10	4
03	Aluminum plate with Ø10 through hole	1
04	Aluminum plate with M10 x 1.5 through thread	1

Table 2 - Elements involved in the test.

In summary, each set of screwed joints is made up of 4 hexagonal head screws - M10 x 1.5 - 26 mm long, measured using a height tracer, resistance class 8.8, with black phosphate surface treatment. Four steel flat washers were also used, according to DIN 125, with a thickness of 3 mm. All elements of the set were inspected for physical and structural integrity, with the clear objective of ensuring smooth results. To keep the screwed joints fixed, in a static condition, a workshop bench was used fitted with a Metalsul N°5 bench vise (5" = 127 mm). After preparing the tests, with the tools in hand, we applied a torque of 100% of the yield stress of the material (aluminum), with the aim of shearing the female threads belonging to the bottom plate (Figure 5).

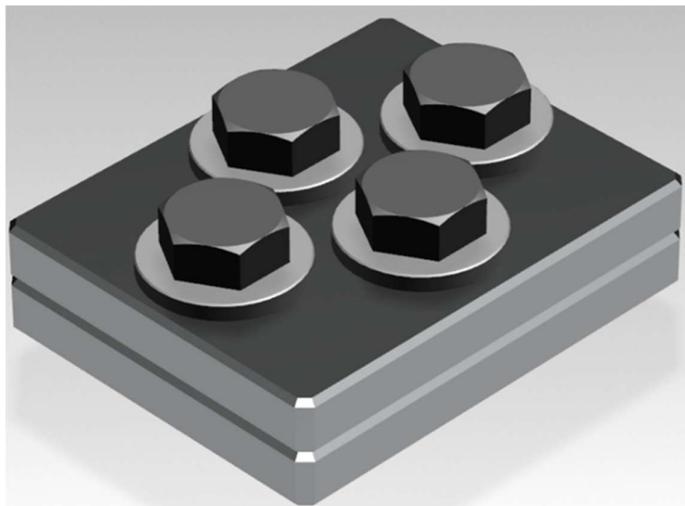


Figure 5 - Arrangement of elements in the bolted joint.

In this study, a torquemeter was also used. Torque wrenches are hand tools that are used to precisely and specifically adjust the tightening torque of threaded elements. Such dynamometric tools incorporate a force or weight measurement system that allows them to be used with maximum precision. Electronic digital torque wrench with microprocessor control, Torcotronic 8455-120 – Gedore, with nominal capacity of 120 Nm, with permissible error: +/- 1%, memory function up to 2000 values, to measure torque and tightening angle, USB interface for data exchange with PC, angle and torque measurement accuracy +/- 1%, torque resolution equal to 0.1 Nm, torque angle resolution: 0.1°, and ability to convert data to Microsoft Excel. A helicoil kit with tools was also purchased at a tool store for the metalworking industry. The kit contains the following components: 20 threads – helicoil, one special tap for helicoil M10x1.5 insertions. This action makes it impossible for the false thread to be removed from the housing.

Tests were carried out on 6 complete sets, namely:

- 3 complete sets with bottom plate drilled by HSS drill and thread machined by male M10x1.5.
- 2 complete sets with the lower plate reworked in the thread region, resulting from the previous test, and false threads introduced in the position of the damaged threads. Machining with a single tap, specific to the helicoil kit.
- 1 complete set with the lower plate already fitted with a false thread.

3. RESULTS

A possible shear failure mode involves thread tearing of both the nut and the bolt. If the material of the nut or threaded part is larger, its threads can be cut along its larger diameter. If the bolt is weaker, it may have its threads torn along its smaller diameter. If both materials have identical strength, the assembly can be torn along the pitch diameter. In any case, we must assume some degree of load sharing between the threads in order to calculate stresses.

One way to proceed is to consider that since a complete failure requires all threads to be torn, the threads can be considered as sharing the load equally. This assumption is probably valid as long as the nut or bolt (or both) is ductile so as to allow each thread to tear as the assembly begins to fail. However, if both parts are brittle (e.g. high strength steels or cast iron) and the fit of the threads is poor, we can imagine each thread taking on the full load in turns until it fractures and the work is passed on to other threads. the next fillet. The reality is embedded in these extremes. If we express shear stress in terms of the number of threads engaged, judgment must be made in each case to determine the appropriate degree of load sharing.

Considering that the tests were carried out using the same method, equipment, labor, and aspects such as coefficient of friction (μ_C), yield of fasteners (η), were assigned according to the manufacturer's catalog, and also, As the torque applied was aimed at extracting the maximum force from the bolted joint, raising the bolts and threaded plate to the limit of tensile strength and flow in the threaded region, we found results consistent with the specification of the elements.

Tests with Thread in the Aluminum Plate 3003												
Sample	Torque [Nm] (Failure)	dp [mm] (Bolt)	dr [mm] (Bolt)	At [mm ²] (Bolt)	τ torsion [kNm] (Bolt)	LRT [MPa] (Plate)	LRT [MPa] (Bolt)	F [kN] (Bolt)	T [Nm] (Bolt)	LRT [MPa] (Helicoil)	F [N] (Helicoil)	T [Nm] (Helicoil)
A1	72	9.0257	8.1598	57.9904	199.2233	150	800	46.4	---	---	---	---
A2	63	9.0257	8.1598	57.9904	174.3204	150	800	46.4	---	---	---	---
A3	72	9.0257	8.1598	57.9904	199.2233	150	800	46.4	---	---	---	---
A4	67	9.0257	8.1598	57.9904	185.3884	150	800	46.4	---	---	---	---
A5	71	9.0257	8.1598	57.9904	196.4563	150	800	46.4	---	---	---	---
A6	70	9.0257	8.1598	57.9904	193.6893	150	800	46.4	---	---	---	---
A7	70	9.0257	8.1598	57.9904	193.6893	150	800	46.4	---	---	---	---
A8	67	9.0257	8.1598	57.9904	185.3884	150	800	46.4	---	---	---	---
A9	68	9.0257	8.1598	57.9904	188.1553	150	800	46.4	---	---	---	---
A10	72	9.0257	8.1598	57.9904	199.2233	150	800	46.4	---	---	---	---
A11	66	9.0257	8.1598	57.9904	182.6214	150	800	46.4	---	---	---	---
A12	63	9.0257	8.1598	57.9904	174.3204	150	800	46.4	---	---	---	---
Average	68.4	9.0257	8.1598	57.9904	189.3083	150	800	46.4	---	---	---	---

Table 3 - Table of torque results on the plate with M10 x 1.5 thread

Therefore, for the first tests, where the thread machined in the aluminum plate did not support the force exerted by the bolt and this, in turn, did not identify effects of elongation, deformation or another visual anomaly. This behavior occurred in all bolts subjected to maximum torque. The 12 tapped holes were damaged by the same failure mode, with extremely similar characteristics.

The results printed in Table 3 show that the bolt thread withstood the torque very well compared to the aluminum plate thread, causing the plate thread to collapse. This is a notable fact, considering the material used in the test. Figure 6 shows the presence of thread fillets in the body of the bolt, an effect characterized as Thread Stripping. Note that the results of the applied torques were very concentrated, but with points outside the 10% considered acceptable in the study. Possibly due to lack of control of fasteners, accurate control of threads and even dimensional variation of bolts.

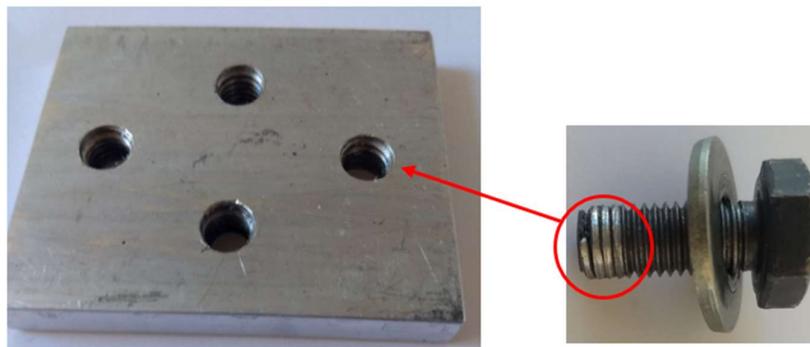


Figure 6 - Plate with damaged thread after torque application

In the second tests, where the proposal was to insert the bolt thread – helicoil, and again subject the set to a new torque, raising the threads (internal/external) to the maximum of their forces, without considering the resistance limit of the bolts.

Testing with the use of false threads in the Aluminum Plate 3003												
Sample	Torque [Nm] (Failure)	dp [mm] (Bolt)	dr [mm] (Bolt)	At [mm ²] (Bolt)	τ torcional [kNm] (Bolt)	LRT [MPa] (Plate)	LRT [MPa] (Bolt)	F [kN] (Bolt)	T [Nm] (Bolt)	LRT [MPa] (Helicoil)	F [N] (Helicoil)	T [Nm] (Helicoil)
A1	116	9.0257	8.1598	57.9904	320.9709	150	800	46.4	92.8	1400	81.2	162.4
A2	107	9.0257	8.1598	57.9904	296.0680	150	800	46.4	92.8	1400	81.2	162.4
A3	117	9.0257	8.1598	57.9904	323.7379	150	800	46.4	92.8	1400	81.2	162.4
A4	106	9.0257	8.1598	57.9904	293.3010	150	800	46.4	92.8	1400	81.2	162.4
A5	106	9.0257	8.1598	57.9904	293.3010	150	800	46.4	92.8	1400	81.2	162.4
A6	113	9.0257	8.1598	57.9904	312.6699	150	800	46.4	92.8	1400	81.2	162.4
A7	109	9.0257	8.1598	57.9904	301.6019	150	800	46.4	92.8	1400	81.2	162.4
A8	107	9.0257	8.1598	57.9904	296.0680	150	800	46.4	92.8	1400	81.2	162.4
A9	112	9.0257	8.1598	57.9904	309.9029	150	800	46.4	92.8	1400	81.2	162.4
A10	115	9.0257	8.1598	57.9904	318.2039	150	800	46.4	92.8	1400	81.2	162.4
A11	108	9.0257	8.1598	57.9904	298.8350	150	800	46.4	92.8	1400	81.2	162.4
A12	107	9.0257	8.1598	57.9904	296.0680	150	800	46.4	92.8	1400	81.2	162.4
Average	110.3	9.0257	8.1598	57.9904	305.0607	150	800	46.4	92.8	1400	81.2	162.4

Table 4 - Table of torque results on the plate with false threads M10x1.5

In the following tests, where the insertion of the false threads – helicoil, were duly carried out, being in two plates already damaged by the previous tests and one completely new, we collected results that were far superior to the studies carried out. This time, there was no shearing of the threads on the plate, the false threads, nor the bolts. Remembering that helicoil has superior hardness, a much nobler material than bolts, tensile strength almost twice as high as bolts. So, it couldn't be different, because we had ductile fracture in the bolts, close to the hex head region. All 12 bolts were damaged by similar failure modes after being subjected to the torque shown in Table 4. Figure 7 shows the fracture on the bolts.

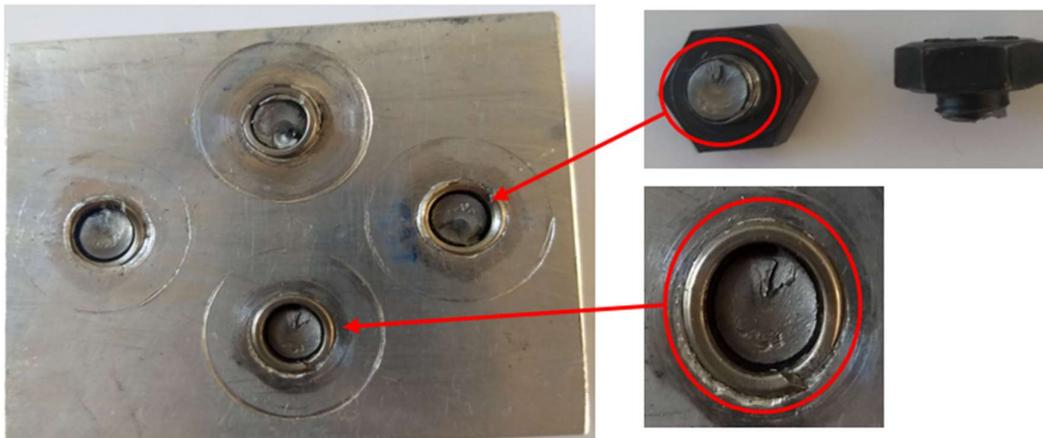


Figure 7 - Fractured bolt after torque application

It is evident that there is a distribution of torques, even on the plates that were reworked. We understand that samples A1, A3, A6 and B10 are far above the normal limits for an 8.8 class bolt, even though they are single box elements. Therefore, we cannot conclude that the regions of the reworked threads suffered structural damage. But we can also observe the deformations in the aluminum plates originating from the washers and superior force being applied to the set. It is also noted that the false thread - helicoil, the helicoil remained intact inside the aluminum plate. Possibly after extracting the residuals from the bolts, we could still use this threaded region without loss of properties.

4. CONCLUSION

In this study, an experimental investigation was carried out on the shearing of the threads of an aluminum plate and subsequent insertion of false threads - helicoil, attributing to the plate a greater torsional efficiency in the threaded region. Certain projects should assume these elements as a primordial and necessary factor for the purpose of a longer life of the components. With the use of false threads, it was possible to assign a little more than 50% of the average initial torque to the bolts. This implies a greater extraction of strength from the bolted joint by promoting the use of higher grade bolts in thinner plates. A disadvantage of this element is that if the technician/maintainer is not well instructed in the correct application of torque, it may fracture the bolt inside the bolted joint, causing enormous difficulty in removing it or even rendering the threaded component unusable.

During this work, some lines of research could have been conducted, but in order not to deviate from the proposed initial focus, it is suggested that other investigations be carried out. This could enrich the knowledge of this subject for

eventual consumers of this technical resource. It would be possible, for example, to verify the pullout load of the false threads through tensile and compression tests or use better class bolts (12.9) for checking the maximum torque that this joint would support after installing the helicoil. There is a huge range of tests and results that could have been extracted from this work, but one thing was very clear: the use of false threads is a very efficient way of recovering a threaded part, promoting a longer useful life of the threaded joints.

5. ACKNOWLEDGEMENTS

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