

An Empirical Model to Calculate the Threads Stripping of a Bolt Installed in a Tapped Part

Manuel Martínez Martínez, and Daniel Zavala Ríos

Abstract—To determine the length of engagement threads of a bolt installed in a tapped part in order to avoid the threads stripping remains a very current problem in the design of the thread assemblies. It does not exist a calculation method formalized for the cases where the bolt is screwed directly in a ductile material. In this article, we study the behavior of the threads stripping of a loaded assembly by using a modelling by finite elements and a rupture criterion by damage. This modelling enables us to study the different parameters likely to influence the behavior of this bolted connection. We study in particular, the influence of couple of materials constituting the connection, of the bolt's diameter and the geometrical characteristics of the tapped part, like the external diameter and the length of engagement threads. We established an experiments design to know the most significant parameters. That enables us to propose a simple expression making possible to calculate the resistance of the threads whatever the metallic materials of the bolt and the tapped part. We carried out stripping tests in order to validate our model. The estimated results are very close to those obtained by the tests.

Keywords—Bolt, damage, plasticity, stripping, thread assemblies.

I. INTRODUCTION

ONE of the essential problems of calculation of the thread assemblies is to avoid the threads stripping before the rupture of the bolt occurs. Indeed, at the time of the setting in prestressing, due to the inaccuracy of tightening, it is possible to cause the beginning of the shearing of the threads without their complete stripping. Under such conditions, the threads are damaged without being visible. The setting in operation of such assembly can generate catastrophic effects. It therefore should be made sure that in the event of overstressing, the bolt will break before the threads stripping. This problem has to be solved by calculating the length of minimum engagement of the threading which answers to this condition. Of course, it is still possible to take a very big length of engagement but in this case, the assembly will not be optimized and it is however this which is asked in a large number of industrial sectors.

When the materials of the bolt and the tapped part have a comparable resistance, the installation of a length of engagement threads ranging between 0.8 and 1.5 times the

bolt diameter is sufficient to ensure that, in the event of rupture, it is the bolt that will break. Nevertheless, this calculation rule is not sufficient if the materials are very different as if the external diameter of the tapped part is not bigger than the bolt diameter. Generally, the bolts are made of more resistant materials than those of the assembled parts. The length of engagement threads has then to be calculated correctly to improve the stripping strength and to envisage this type of failure. In this case, calculation rules [1-3] allow us, to consider more or less good the stripping strength of the threads.

The goal of this article is to propose a precise and simple analytical model to enable the designer to make these calculations quickly and at the lowest cost. To achieve this, we have studied the behavior of a thread assembly made up of a bolt and a tapped part. The procedure used in our work enabled us to obtain precise results as well as a wider control of the parameters of the problem. This procedure is based on the use of an axisymmetric finite elements model and a criterion of rupture by damage. We take account of the contact and the plasticity of the materials. We carried out a study of behavior according to the dimensions and materials of the assembly by applying a static charge. That enabled us to demonstrate well adequately the effect of the most significant parameters such as the bolt diameter, while some of these parameters only were mentioned until now in literature.

In the next pages, we will present:

- The finite elements model and calculation procedure,
- The study of the parameters influencing the thread assembly,
- The proposed equation for the charge calculation to the threads stripping,
- Analysis of the results.

II. FINITE ELEMENTS MODEL AND CALCULATION PROCEDURE

Given the high number of calculation cases to treat, we supposed, to avoid important computing times, that the bolt and the tapped part had an axial symmetry. Moreover, we neglected the helicoidal angle of threading. These hypotheses enabled us to use an axisymmetric model, already used by us for the calculation of nut thread stripping in a bolt and nut assembly [4, 5].

Both internal and external threads with large pitch are defined by the standard ISO NF E03.001/ISO 68. The

Authors are with the Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM) Campus Tampico. Tampico, Tamaulipas., México (manuel.mmartinez@itesm.mx*, daniel.zavala@itesm.mx+, phone: +52-833-2291600 ext. 2233).

materials used have elastoplastic characteristics. We took friction and slip between contact surfaces, and unsticking is also permitted. A static load is applied in traction to the bolt.

We carried out a mapped mesh of the engagement threads because it is where the major concentration of plastic deformation is. For the remaining areas, we carried out a free meshing to reduce the solution time. We used axisymmetric elements of first order (4 nodes) of reduced integration with isotropic characteristics and elastoplastic material with work hardening. (Fig. 1)

We carried out a convergence study of results at the level of the threads stripping, of local plastic strain and local stresses for each diameter used in our analysis.

To envisage the charge at the instant of the failure, we followed the same procedure as in [4]. When the plastic deformation of the most damaged element, calculated by software (ABAQUS) is practically equal to the one calculated from the criterion of rupture by damage [7], we record the applied load. This value corresponds to the charge at the beginning of the threads stripping, in this case that of the tapped part. We noted in [5] that this calculation procedure gives results which are very close to those obtained by stripping tests.

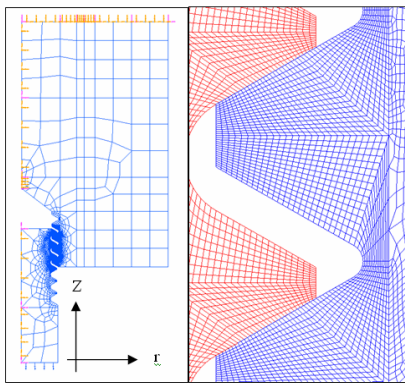


Fig. 1 Finite elements model. On the left side, the axisymmetric model. On the right, threads in contact

III. PARAMETERS STUDY

To develop an expression of calculation without resorting to the individual case study, we carried out a qualitative study to demonstrate the effect of the different parameters influencing the behavior of the thread assembly.

A. Effect of the Length of Engagement Threads (L_e)

We varied the length of engagement threads (L_e) in our finite elements model. The couple of materials, the bolt diameter and the tapped part geometry remained constant during simulations. Then we recorded the stripping load for each L_e value. We noted that the development of the load at the macroscopic crack initiation according to the length of engagement threads is almost linear (Fig. 2).

The results also show that the load which causes the fracture initiation in the first element being mostly damaged is very close to the load which causes the complete stripping of

threading, this thanks to present damage on the threads remaining. We carried out step-by-step simulations by using the "elements removing" technique proposed by ABAQUS [8], from the rupture of the first thread until the last one. We noted that a small increment of load was enough to tear off threading completely. On the other hand, we realised that the linear development of the load, which causes the rupture of the first element, depends on the tapped part material. Indeed, when this material is very ductile in relation to that of the bolt, this development moves away appreciably from the linearity which one finds to the complete stripping of threading.

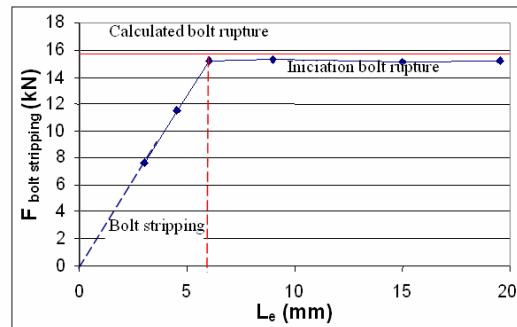


Fig. 2 Development of the F load according to L_e

As we noted in [5], this simulation procedure of threads stripping gives results very close to those obtained by the tests.

B. Effect of the Ultimate Resistance (R_{mB}) of Bolt Material

We studied the behavior of the threading of the bolt at the time of stripping according to the bolt material. For this, the parameters already mentioned remain constant except the characteristics of the couple of materials which has been varied. We have demonstrated the fact that the development of the load up to the onset of failure (F) remains linear in relation to the material ultimate resistance of the bolt. (Fig. 3)

We also studied this behavior by changing the other parameters and in all the cases we found the same linear development well, but of course, with different slopes. (Fig. 3).

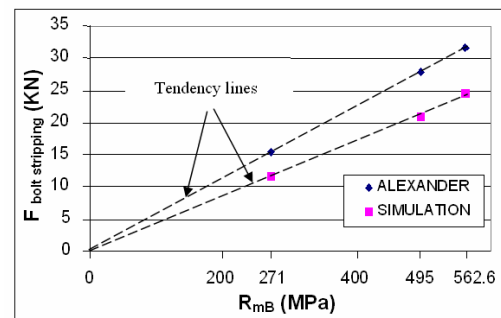


Fig. 3 Development of the F load according to R_{mB}

C. Effect of the Couple of Materials

We varied the characteristics of the material of the tapped part for each material of the studied bolt. We involved the

relationship between material ultimate resistance of the tapped part and the material ultimate resistance of the bolt (R_{mN}/R_{mB}) will be named resistance ratio (R_{ms}). We varied this ratio for each value of (R_{mB}) and for various values of the other parameters. We noted that this behavior also depends on the external diameter of the tapped part. (Fig. 4)

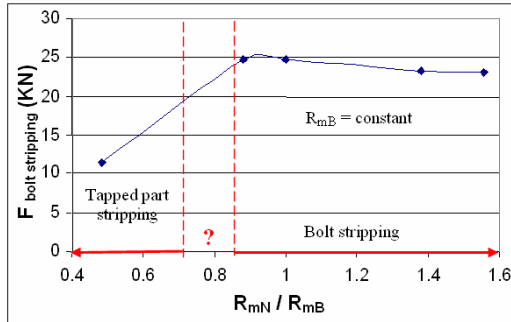


Fig. 4 Development of the F load according to Rms

It should be noted that below $R_{ms} = 0.73$, the threads stripping of the tapped part occurs without apparent deterioration of the bolt threads [5, 6]. Also up to $R_{ms} = 0.88$ value, the threads stripping of the bolt occurs, like we noted it by tests in [5].

D. Effect of the External Diameter of the Tapped Part

This parameter determines the radial rigidity of the tapped part and therefore influences its radial mechanical dilation due to the contact pressure exerted by the bolt threads. Indeed, a reduction of the external diameter has for consequence an increase of the radial dilation of the tapped part and reduces its stripping strength of the threads. The evolution of these parameters is good related with that of the bolt diameter; for that reason, we retained the ratio of the external diameter of the tapped part to the bolt diameter (D_{ext}/d) as a significant parameter.

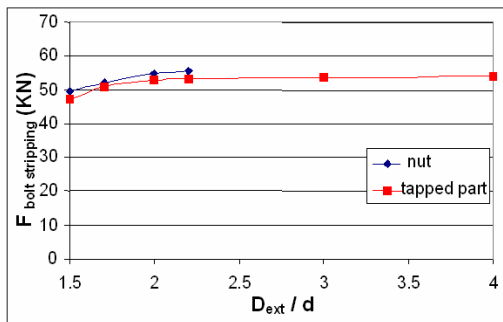


Fig. 5 Development of the F load according to Dext/d

Additionally, we examined the influence of the R_{ms} ratio on the effect of the D_{ext}/d parameter. To the higher limit of R_{ms} the development of the load according to D_{ext}/d becomes asymptotic for $D_{ext}/d > 2.0$. Therefore we concluded that above this value the increase of the external diameter does not have more additional effect on radial rigidity. (Fig. 5).

E. Effect of the Bolt Diameter (d)

The nominal bolt diameter is the fifth parameter, which we studied. We obtained a good linearity between the development of the charge of stripping and the diameter of the bolt, Fig. 6. We varied this parameter for values ranging between 6 and 20 mm by fixing (D_{ext}/d). Also we varied the R_{ms} ratio. For different values of this parameter, we obtained the same behavior, Fig. 6.

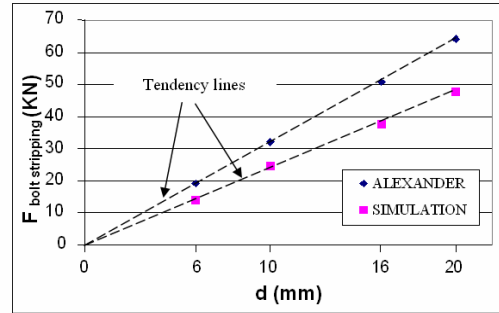


Fig. 6 Development of the F load according to d diameter for $D_{ext}/d = 3$.

IV. SETTING UP AN EXPERIMENT DESIGN

As we indicated previously, the load F which causes the stripping of threads of a certain bolt can be written: $F = f(L_e, R_{mB}, R_{ms}, D_{ext}/d, d)$. It therefore acts for us to determine this function using an experiment design to propose an analytical formula to calculate this F load.

For a given bolt diameter, an engagement length and a type of material of the tapped part fixed, we retained two parameters to study, R_{ms} and D_{ext}/d . We studied the influence of these parameters using a complete factorial experiments design at three levels because they both have a quadratic behavior, Table I.

TABLE I
LEVELS OF EXPERIMENT DESIGN PARAMETERS

Level	R_{ms}	D_{ext}/d
1	0.88	1.5
2	1.38	1.7
3	1.55	2.0

From the results of the experiments design, we built a second-degree model for the stripping load for a bolt in XC38, with a bolt diameter of 10 mm and an engagement length of 4.5 mm, equations (1-6).

For $0.88 < R_{ms} < 1.55$

$$A_1 = 27.5635 R_{ms} - 10.1981 R_{ms}^2 \tag{1}$$

For $R_{ms} \geq 1.55$

$$A_1 = 18.2225 \tag{2}$$

$$\text{For } 1.5 < \left(\frac{D_{\text{ext}}}{d} \right) < 2.0$$

$$A_2 = 91.991 \left(\frac{D_{\text{ext}}}{d} \right) - 24.89765 \left(\frac{D_{\text{ext}}}{d} \right)^2 \quad (3)$$

$$\text{For } \left(\frac{D_{\text{ext}}}{d} \right) \geq 2.0$$

$$A_2 = 84.3894 \quad (4)$$

$$\text{For } 0.88 < R_{\text{ms}} < 1.55 \text{ and } 1.5 < \left(\frac{D_{\text{ext}}}{d} \right) < 2.0$$

$$A_3 = 2.06328 R_{\text{ms}} \left(\frac{D_{\text{ext}}}{d} \right) \quad (5)$$

$$F_{\text{particular case}} = F_{\text{bolt stripping XC38, d=10mm, Le=4.5mm}}$$

$$F_{\text{particular case}} \text{ (kN)} = -82.71533 + A_1 + A_2 + A_3 \quad (6)$$

As we checked by simulations this F load was linear in relation to R_{mB} , d and L_e , we generalised this model to all materials of the bolt, to all bolt diameters and to all engagement lengths.

We obtained the equation below, which allows the calculation of the load causing the beginning of threads stripping in a bolt. Within the limits of the proposed parameters, this load is appreciably the same one as that which causes the complete stripping of threads.

$$F \text{ (kN)} = \left(\frac{-82.71533 + A_1 + A_2 + A_3}{25317} \right) d R_{\text{mB}} L_e \quad (7)$$

V. COMPARISON OF RESULTS

We validated equation (7) in relation to simulations and the tests. Indeed, we compared the results obtained from this equation with the simulations results and the tests carried out for different bolt diameters, engagement lengths and materials not used already in the experiment design.

Table II compares the considered F value with the simulated value by finite elements F_{SIMS} and with those obtained by ALEXANDER [1] F_{ALEX} . We conducted paired t-tests, and with a 95% confidence level we concluded that there was not a statistically difference between the results obtained from $F(\text{kN})$ vs. $F_{\text{SIMS}}(\text{kN})$, obtaining a t-value of 2.03. With a 95% confidence level we concluded that there was a statistically difference between the results obtained from $F(\text{kN})$ vs. $F_{\text{ALEX}}(\text{kN})$, with a t-value of -6.30.

TABLE II
SOME RESULTS. COMPARISON WITH SIMULATION RESULTS AND THE EXISTING METHOD

Couple	L_e (mm)	d (mm)	D_{ext}/d	$F(\text{kN})$	F_{SIMS} (kN)	F_{ALEX} (kN)
Cu /St 8.8	5.0	20	1.5	23.1	22.2	33.41
AU4G /IN100	4.5	10	2.0	22.5	20.58	31,30
XC38 /St 8.8	4.0	16	1.5	33.2	29.66	43.72
Cu /St 12.9	4.0	16	1.5	15.2	14.07	21.40
AU4G /St 10.9	4.0	6	2.0	12.65	10.83	16.32
XC38 /35NC16	4.5	10	1.7	28.31	29.3	34.51
Cu /St 12.9	4.0	6	1.7	5.28	5.57	8.67

VI. CONCLUSION

To our knowledge, a model making possible to calculate the stripping of threads of bolts does not exist. There exists an industrial need for optimising this type of assembly which one generally answers by carrying out tests. Our study propose a partial solution to this problem by giving an analytical model of calculation of the load which causes the stripping threads of a bolt in a tapped part whose material is more ductile than that of the bolt. This model is valid only in the field of variation of the studied parameters which covers all the same a very broad range of use in particular that of general mechanical engineering. As it can be seen in our results, the calculations carried out by our analytical model, are not statistically different from those calculated by the F_{SIMS} software. This represents an important contribution, especially for those workshops which can not afford the acquisition of specialised software.

REFERENCES

- [1] Alexander E M, *Analysis and Design of Threaded Assemblies*, Int. Automotive Eng. Congress and Exposition, Detroit, 1977, Ref. No 770420.
- [2] Dose G.F., Pittner K.J, *Neuartige Berechnung von Schrauben unter Berücksichtigung der Werkstoffkennwerte.*, Konstruktion, 1996, 48.
- [3] Thomala, *Zur Berechnung der Erforderlichen Mutterhohe Bei Schraubenverbindungen*, Konstruktion, 1995, 47.
- [4] Martinez-Martinez M, Ferrand A, Guillot J, *Finite Element Analysis of Thread Stripping of a Threaded Assembly*, Computational Methods in Contact Mechanics V, J. Dominguez and C. A. Brebbia, WITPRESS , 2001, pp. 263-272.
- [5] Martinez-Martinez M, Ferrand A, Guillot J, *Calculation of Nuts Threads Stripping*, Proceedings of 2001 ASME International Mechanical Engineering Congress and Exposition, November 11 to 16, 2001, New York, NY. To be published.
- [6] Martinez-Martinez M, Ferrand A, Chaussumier M, *Modelling of Thread Stripping in Tapped Parts*, Proceedings of 2002 IDMM, May 14 to 16, 2002, Clermont-Ferrand, France.
- [7] Chaboche L, 1988, *Continuum Damage Mechanics, Parts I and II*, J Appl. Mech., 55, pp. 59-72.
- [8] ABAQUS/Standar User's Manual, Volume 1, version 5.8.