



Finite element analysis of thread stripping of a threaded assembly

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Abstract

In this paper, we study the nut thread stripping of a loaded threaded assembly by using finite element modeling and a criterion of damage. The aim is to envisage the appearance of the macroscopic fissure which characterizes the beginning of stripping. We compare that result with those obtained by tests and other formulations existing in the literature.

We carried out tests of stripping of threads. The threaded assembly is composed of an M10 bolt and a round nut of which we will vary the height. The materials used are steel class 12.9 for the bolt, copper and the AU4G for the nuts.

In this work, we considered that the material presents an irreversible damage just before the macroscopic fissure occurs. We used the expression suggested by LEMAITRE and CHABOCHE in their theory of the damage in mechanics of the continuous mediums, for the calculation of the plastic deformation due to rupture. By using the results of simulation given by ABAQUS for various levels of load, we calculated the maximum plastic deformation due to the rupture at the place considered as being deformed the most.

We carried out an analysis that represents in a satisfactory way the reality of the phenomenon of thread stripping of a nut screwed in an M10 bolt. We validated this model by carrying out tests of thread stripping for various materials. The results obtained by our model, are very close to those obtained by the tests and not very far away from the other authors. This is of great importance for the continuation of our work because this model should enable us to envisage the behavior of all possible couples of ductile metallic materials without having to use to systematic tests.



1 Introduction

The rupture of an assembly can occur in three different ways: by bolt breaking, by nut thread stripping, or by bolt thread stripping Alexander[1], Thomala[2,3]. Existing research allows the precise dimensioning of the bolt for different applications of loads, and it is generally possible to envisage its rupture.

With regard to the thread stripping, there is a rule very simple Bickford[4] which makes it possible to calculate the length of thread engagement of a nut or a tapping when the materials of the bolt and nut or tapping are identical. This one consists on installing a length of engagement from 0.75 to 1 time the diameter of the bolt, which guarantees that, if there is a rupture, in fact it is the bolt that will break. In this case, the corrective action become obvious.

If this rule is sufficient when we use same materials for the bolt and the nut, it is very insufficient, even dangerous, when we install the bolt in a tapping carried out on a part from which the material is different. Indeed, if during tightening there is stripping without rupture, phenomenon which can not be visible, a danger will exist at the time of the startup.

In this article, we study the behavior of the threads of a loaded threaded assembly by using finite element modeling and a criterion of damage. This with an aim of envisaging the appearance of the macroscopic fissure which characterizes the beginning of stripping. We compare then the results obtained by calculation in finite elements with those obtained by tests and other formulations existing in the literature. Thanks to such a model, we will be able to study in the future the influence of the various parameters much more easily than by systematic tests.

1.1 Notation

D	bolt diameter.
p_R	magnitude of accumulated plastic deformation at the rupture.
E	elasticity modulus.
F	maximum force during threads stripping.
K	plastic coefficient of material resistance.
L_e	length of thread engagement.
M	coefficient of work hardening of material.
Re	elastic limit.
R_m	ultimate stress.
ϵ_v	true or real deformation.
ϵ_{pl}	unidimensional plastic deformation.
ϵ_R	unidimensional deformation due to the rupture.
σ_v	true or real stress.
σ_{eq}	Von Mises equivalent stress.
σ_H	hydrostatic stress.
ν	Poisson's ratio.

2 Finite element model of a threaded assembly

2.1 Model description: geometrical and mechanical characteristics

Initially, we have limiting the problem to the case of a simple assembly where the bolt is requested in traction, figure 1. Nut and bolt threads are defined by the standard ISO NF E 03.001/ISO 68 Guillot[5].

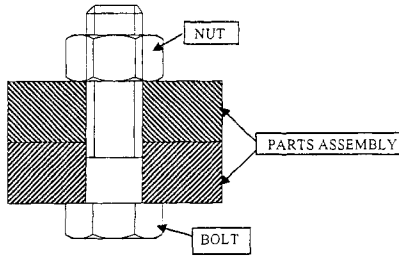


Figure 1: Studied model.

The model is regarded as being axisymmetric and is limited to the cylindrical cases of parts with a concentric hole compared to the external diameter of the assembled parts, figure 1. Given that we want to study only the behavior of the thread engagement, we isolate the nut, the upper part that is in contact with it, and part of the bolt as we made in our previous study of the calculation of the stiffness of nuts Ferrand[6]. Figure 2 shows the model with a mesh of the isolated part. We consider that the three parts are made of different metallic materials whose elastoplastic characteristics were obtained from simple tensile tests in static. To deal with the problem of contact with friction, we retain the following assumptions:

- All the thread engagements are in contact at the beginning of simulation
- There is friction between surfaces in contact and the slip is possible
- The separation of surfaces in contact is allowed during simulation
- The effort is applied in the axis of the bolt.

2.2 Discretization of the finite element model

The model studied in finite element was carried out using the software IDEAS, for all that relates to the geometry, the boundary conditions, loading, as well as meshing. Afterwards, we used the software ABAQUS to supplement the model and to carry out calculations.

2.2.1 Boundary conditions

- We consider that the base of the part is embedded in the vertical direction
- We impose an axisymmetric pressure on the bolt, figure 2. This pressure is a variable to determine according to the criterion of rupture used.

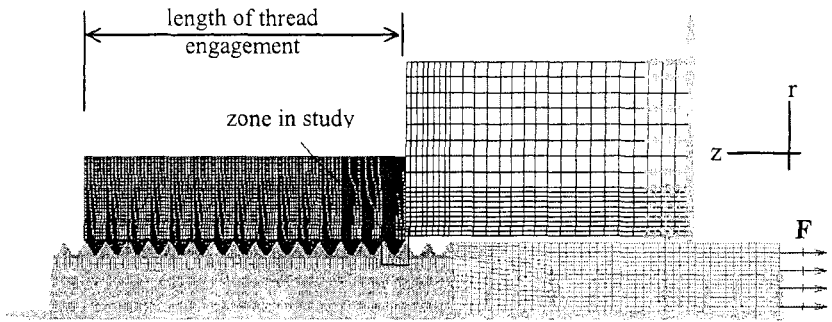


Figure 2: Boundary conditions and mesh.

2.2.2 Mesh

We carried out a regulated meshing, figure 2, with the following physical properties:

- solid axisymmetric hybrid elements of first order (with 4 nodes), with reduced integration
- isotropic and elastoplastic material with work hardened .

2.3 Modes of rupture of a threaded assembly

The behavior of a threaded assembly under static charge can present three modes of rupture.

- Rupture by shearing of the threads (thread stripping) of the nut or tapping, when the material of the nut has a lower resistance than that of the bolt and/or when the length of thread engagement is very low.
- Rupture by shearing of the bolt thread, when the material of the internal threads is relatively more resistant than that of the nut.
- Rupture of the bolt, when the length of engagement is sufficiently significant and the material of the nut has a resistance comparable to that of the bolt.

According to the research Zhao[7], these types of rupture begin not far from the first committed thread (close to the part support), see figure 2, due to a great plastic deformation and stress concentration.

2.4 Convergence study of the mesh refinement. Case of the nut threads stripping

In this first part, we studied the case of the nut threads stripping. We carried out simulations by finite element for different combination of material bolt-nut-part. The results show a concentration of plastic deformation at the point where the first bolt thread is in contact with that of the nut. This point is close to the

bottom of the first nut thread. This is why this zone is most significant to our study.

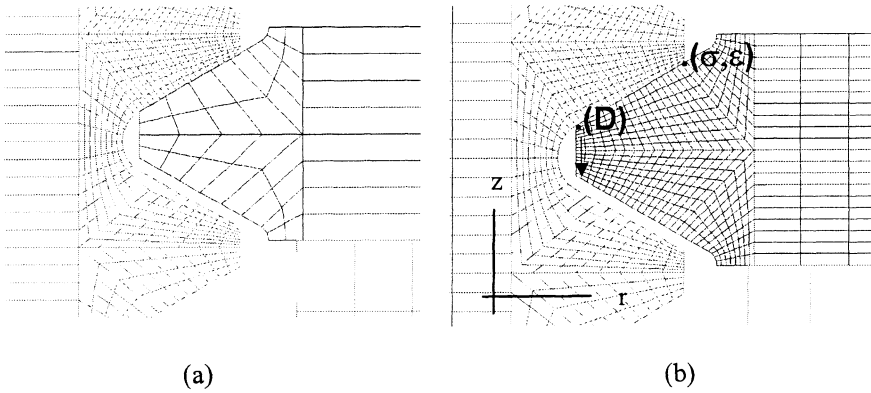


Figure 3: Mesh refinement. (a) Coarse. (b) Refined.

To ensure the convergence of the results of simulation, we gradually refined the mesh on the basis of a coarse mesh, figure 3. We considered the influence of the density of the mesh in two points of the same zone. These points are indicated on the figure 3b (D is the displacement in $-Z$ direction). The study of the convergence of these results is shown in figure 4. These results are normalized compared to the values obtained in simulation by finite element by using the coarsest mesh. Thus, we checked that, in spite of the presence of a singular point, we obtained a convergence of the results according to the refinement used.

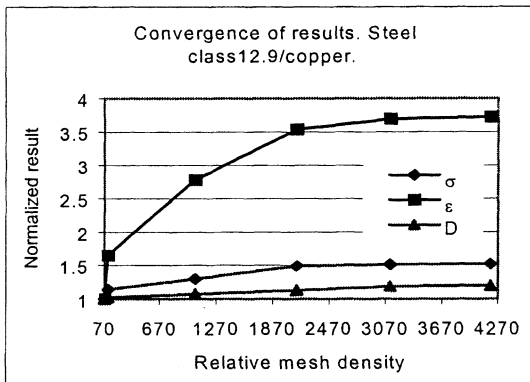


Figure 4: Study of mesh refinement.

3 Elastoplastic behavior of material

To carry out simulation, it is necessary to define the elastoplastic behavior of material. It is necessary to have the knowledge of the modulus of elasticity E , the elastic limit Re and the plastic behavior $\sigma = f(\epsilon_{pl}, K, M)$. These parameters are obtained from the tensile test results in static which we carried out on the same brutes that we used to produce the aluminium AU4G and copper nuts. These parameters are indicated in the following table. In particular, these tests enabled us to determine the parameters K and M for a hardenable elastoplastic behavior in unidimensional deformation for an initially isotropic solid, in loading static Lemaitre[8-10], eqn (1).

$$\sigma = K \left(\epsilon_{pl} \right)^M \quad (1)$$

Table 1. Parameters characterizing materials.

Material	E (MPa)	Re (MPa)	Rm (MPa)	K	M
Copper	112589	118.7	271	365.8	7.91
AU4G	71590	398.3	504	611.5	16.8
Steel class 12.9	210992	1080	1434	1910	16.1

4 Results of simulations

To get a limit value to stop the simulation procedure, we used a rupture criterion that corresponds to the starting of the macroscopic fissure.

4.1 Criterion of rupture by damage.

In this work, we considered that the material presents an irreversible damage just before the macroscopic fissure occurs. To do so, we used the expression suggested by LEMAITRE and CHABOCHE in their theory of the damage in mechanics of the continuous mediums, for the calculation of the plastic deformation due to rupture p_R Lemaitre[8-13]. This one is given by the following eqn (2):

$$p_R \left(\frac{\sigma_H}{\sigma_{eq}} \right) = \epsilon_R \left[\frac{2}{3}(1+\nu) + 3(1-2\nu) \left(\frac{\sigma_H}{\sigma_{eq}} \right)^2 \right]^{\frac{M}{2+M}} \quad (2)$$

We can note that the plastic deformation due to the rupture depends on the Von Mises equivalent stress σ_{eq} and hydrostatic stress σ_H , as well as other characteristic parameters of materials such as the Poisson's module ν and the plastic coefficient of work hardening M . ϵ_R is an intrinsic constant to each material determined by unidimensional tests, Lemaitre[8,12], for copper $\epsilon_R=1.04$ and alloy AU4G $\epsilon_R = 0.25$.

4.2 Technique of calculation

We varied the length of thread engagement for a M10 bolt. By using the results of simulation given by ABAQUS for various levels of load, we calculated the maximum plastic deformation due to the rupture p_R at the place considered as being deformed the most. Then we compared the plastic deformation limits p_R obtained from eqn (2) with the plastic deformation calculated directly by the software. When the two values are practically equal, we recorded the value of the load applied to the model. This value corresponds to the starting of the macroscopic fissure. See figure 5.

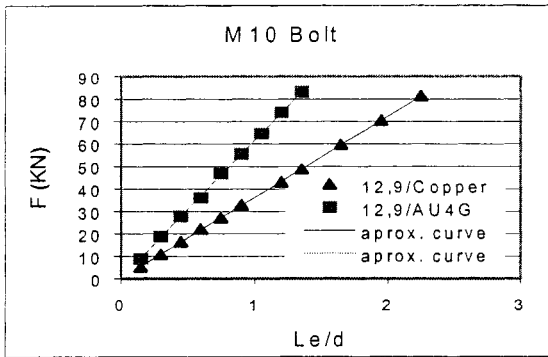


Figure 5: Evolution of the maximum loading (F) in function to ratio (Le/d). Simulation results.

5 Stripping tests of nut threads in static

To check the results obtained in simulations, and in particular the validity of the criterion of rupture proposed, we carried out tests of stripping of threads.

5.1 Preparation of the test-samples and instrumentation

The threaded assembly is composed of a M10 bolt and a round nut of which we will vary the height(length of thread engagement). The materials used are steel class 12.9 for the bolt, copper and the AU4G for the nuts. The unit is assembled on a tensile testing machine, figure 6. The goal of the test is to determine the

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maximum loading reached during the stripping of nut threads. We varied the height of the nut beginning with a value of $Le = 2$ mm and we increased until that bolt broke.

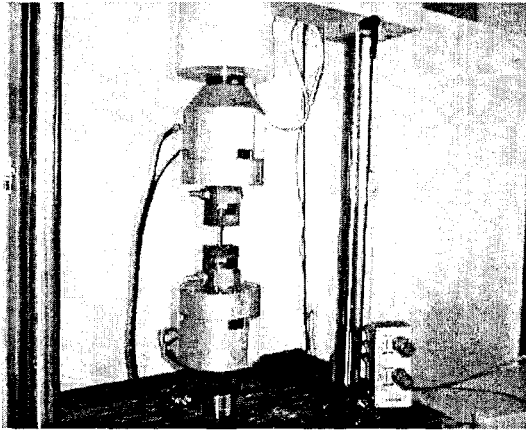


Figure 6: Assembly of the test-samples for stripping of threads.

5.2 Results obtained from the tests

We carried out a series of tests by increasing the effort in the assembly until the threads stripping occurs. We carried out graphs for the two material couples in order to give the evolution of the maximum force according to the length of thread engagement, figure 7. We can note that the load causing the nut thread stripping increases linearly according to the Le/d ratio.

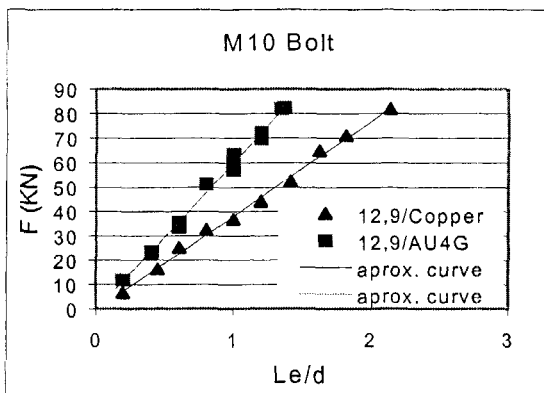


Figure 7: Evolution of the maximum loading (F) in function to ratio (Le/d). Tests results.

6 Comparison of simulation results

After having determined the behavior of the assembly during the application of the limiting load according to the length of threaded engagement, we carried out a comparative study between these results and those obtained from the tests of thread stripping. We also compared the behavior found with current methods Alexander[1], Thomala[2,3], Brelivet[14], Dose[15,16], VDI-2230[17] existing in the literature, figure 8.

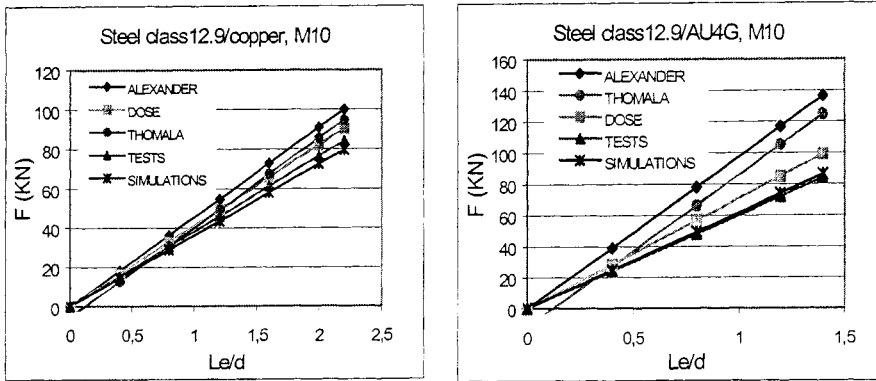


Figure 8: Comparison of simulation results, tests and current methods.

We can note in the following table that the results obtained by our model, are very close to those obtained by the tests and not very far away from the other authors.

Table 2. Errors expressed as a percentage compared to results of the tests.

CASE	ALEXANDER	THOMALA	DOSE	SIMULATIONS
12.9/Copper	+18.18	-10 à 17	+7.33	-5.6
12.9/AU4G	+62.33	13 à 48	+17.8	+2.7

7 Conclusion

We carried out an analysis that represents in a satisfactory way the reality of the phenomenon of thread stripping of a nut screwed in a M10 bolt. We validated this model by carrying out tests of thread stripping for various materials. This is of great importance for the continuation of our work because this model should enable us to envisage the behavior of all possible couples of ductile metallic materials without having to use systematic tests. That will enable us in



particular to evaluate the role of the various parameters like the diameter of the bolt, the diameter of the nut, the materials, the coefficient of friction, etc.

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