14th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2010, Mediterranean Cruise, 11-18 September 2010

FINITE ELEMENT ANALYSIS OF BOLTED JOINT WITH COARSE AND FINE THREADS

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ABSTRACT
In general, most bolt sizes are available in coarse and fine thread optiones. For example, ISO metric coarse and fine pitch series standard – ISO 724:1993 “General purpose metric screw threads – Basic dimensiones” specify the dimensiones for metric threads. Which type of thread is best for a particular application is a common question. In order to give some answers to that questione this paper deals with finite element analysis of generic bolted joint in different load conditions.
Keywords: fine thread, coarse thread, load carrying capacity, finite element analysis

1. INTRODUCTION
Bolted joints are generally made up of the bolt group (head, stud, and nut) and the top and bottom flange (Figure 1). Bolted joint is designed to hold two or more parts together to form an assembly in a mechanical structure (Figure 2).

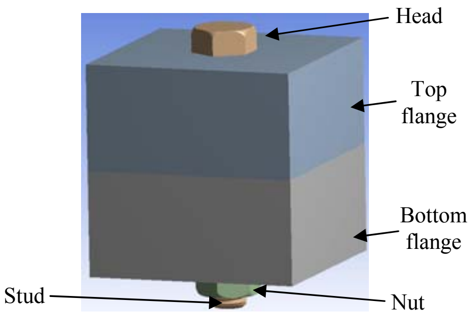

Figure 1. Elements of bolted joint

Figure 2. An assembly with bolted joint

Because of different loading conditions, especially high loads, bolted connections can separate. To minimize this effect, a pretension is applied to the bolt. This insures that the connection will not separate, provided the applied load remains less than the pretension. Thus, two primary characteristics in the bolted joint are a pretension and a mating part contact [1,2].

In order to accurately predict the physical behavior of the structure with a bolted joint, a detailed three-dimensional bolt model is desirable, which fully includes the friction due to the contact on mating parts and pretension effect to tie. This paper deals with finite element modeling of bolted joints with coarse and fine threads in order to reveal their behaviour in different loading conditions.

2. METHOD

2.1 Object of the study

Bolted joints with ISO metric coarse and fine threads (M10x1.5 and M10x1.25) are chosen as the object of the study. In case of metric threads, the thread geometry for fine and coarse threads is defined in a parametric form using the pitch as the determining parameter. As such, the thread form of fine thread will be identical to the thread form of coarse thread in its gross geometric features. Some of the basic dimensiones of the thread (Figure 3) are given in table 1 [3].

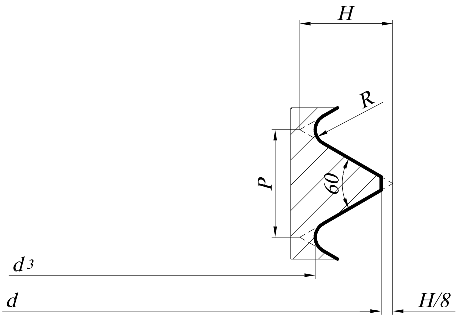

Figure 3. Some basic dimensiones of the thread

Table 1. Basic dimensiones of metric threads M10x1.5 and M10x1.25

Type of thread	Nominal diameter d [mm]	Pitch P [mm]	Minor diameter d_3 [mm]	Root radius R [mm]	Height H [mm]
M10x1.5	10	1.50	8.160	0.217	1.299
M10x1.25	10	1.25	8.466	0.180	1.083

2.2 Analysis of load carrying capacity

Typically, bolts are designed for carrying tensile loads and shear loads. In a tensile bolted joint the most critical parameter is the applied pretension load [4]. In such joints, a fastener that can provide the maximum tensile load is preferable. Similarly, if the bolt is subject to shear loads the effective shear area at the shearing planes needs to be maximized. In general, it is assumed that the failure will occur in the bolt (which is preferable and the design criterion for failure).

In a first order anaysis (assuming total load is evenly distributed over the entire engagement length) on the load carrying capacity of a bolt, it is found to be directly related to the shank diameter. Furthermore, shear failure of the threads should not occur when the bolt is engaged appropriately with the corresponding nut. This means that the threads with larger effective shear areas will be better. The thread profile for ISO metric thread depends on the pitch of the thread, although the general form is the same. Based on the effective tensile stress area of the bolt it could be seen that this area drops as the pitch is increased.

For example, a M10x1.25 bolt has an effective tensile stress area of 61.2 mm^2 while a M10x1.5 bolt will only have 58 mm^2. As such, the failure load of the bolt should be approximately 5.5% larger for the finer pitch bolt. Similarly the thread shear area along the pitch-line per millimeter of the bolt length is 26.57 mm^2 for M10x1.25 bolt and 25.62 mm^2 for M10x1.5 bolt. This gives approximately 3.7% larger thread shear area for the finer threaded bolt. This effectively reduces the minimum engagement length requirement by approximately the same percentage [5]. In essence, the above discussion shows that fine threads are slightly better than coarse threads in terms of load carrying capacity.

If a higher order analysis including the effect of helix angle of the thread and the resulting force resolution is considered, it becomes evident that the higher helix angle inherent to coarse thread will increase the local forces and stresses on the threads [6]. This could lead to bearing failure on the threads and hence galling.

In order to confirm conclusions of previous analysis of load carrying capacity and provide deeper insight in behaviour of generic bolted joint with coarse and fine threads it is conducted a comprehensive finite element analysis (FEA) on a bolted joint in different loading conditions with various pretension and working loads.

Commerciale software Ansys (Ansys, Canonsburg, Pennsylvania, USA) was used for finite element analysis of bolted joint. First, geometric model of bolted joint was generated with ANSYS module DesignModeler. Then ANSYS module Simulation was used to generate the finite element mesh of linear tetrahedral and hexahedral elements (Figure 4). Material of all elements in bolted joint was assumed to be homogenous, isotropic and linear elastic with a Poisson's ratio of 0.3 and an elastic modulus of $2.1 \cdot 10^5$ MPa. The model is loaded with a pretension load and the axial working loads on head-top flange and nut-bottom flange mating surfaces (Figure 5).

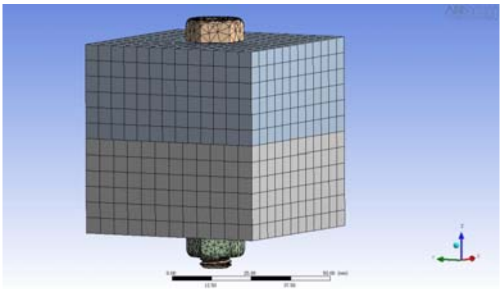

Figure 4. Meshed model of bolted joint

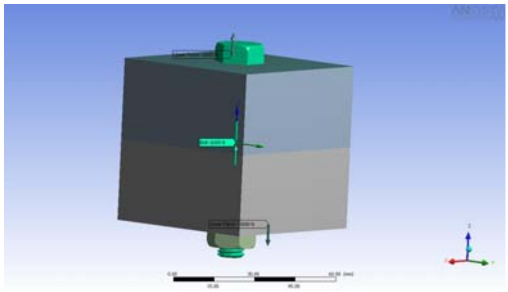

Figure 5. Model boundary conditions

3. RESULTS

Bolted joint is made up of ISO metric M10 bolt and two flanges with thickness of 30 mm. Meshed models of bolted joints with coarse and fine threads was consisted of 95529 finite elements with 144848 nodes and 99731 finite elements with 146813 nodes respectively.

Generated finite element models of the bolted joint were used in a few loading simulations in order to demonstrate the capabilities of the models in studing behaviour of the bolted joint. The finite element models of the bolted joint were subjected to pretension load ranged from 1 kN to 3 kN and axial working load ranged from 0 kN to 150 kN. For the given loads the models were solved for stresses at the nodes (Figure 6).

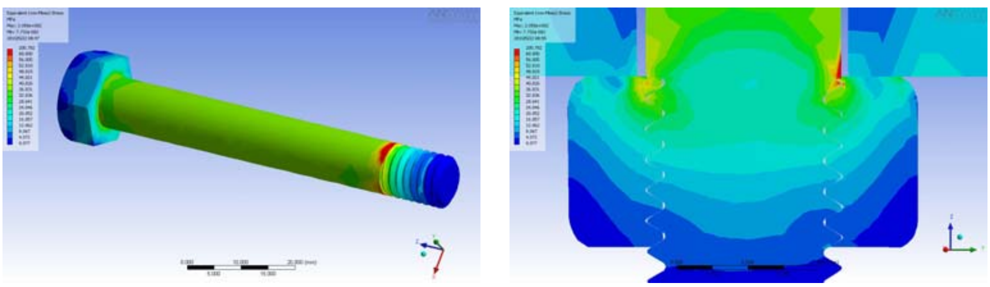

Figure 6. Equivalent von-Mises stress distribution of bolted joint with coarse thread subjected to pretension load of 2 kN and axial working load of 50 kN

Relationships between working load and maximal equivalent von Mises stress based on resultes of finite element analysis of bolted joint with coarse and fine threads are given on figure 7 and 8.

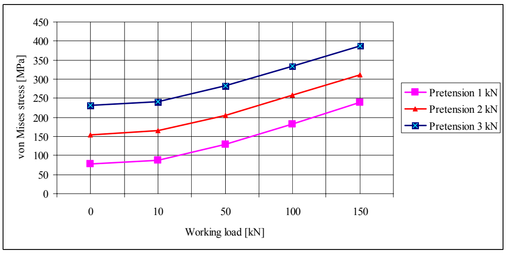

Figure 7. Load–Stress relationship for bolted joint with coarse thread

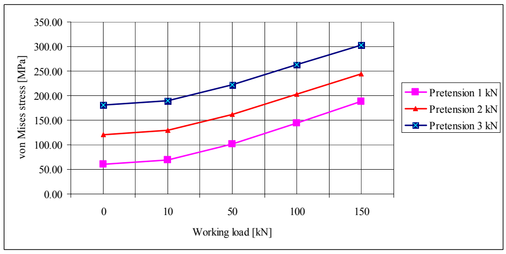

Figure 8. Load–Stress relationship for bolted joint with fine thread

Finite element analysis revealed interesting facts regarding the micro level distribution of stresses. It was found that the coarse threads are not equally loaded and at typical applied loads the first engaged thread (closest to the head) will carry up to 42 % of the applied load. The ensuing threads will carry ≈ 24%, 16%, 11% and 7% respectively. It was also found that the fine threads are not equally loaded and at typical applied loads the first engaged thread (closest to the head) will carry up to 33 % of the applied load. The ensuing threads will carry ≈ 26%, 19%, 11%, 8% and 3% respectively. In both cases any extra threads engaged do not carry any load.

As can be expected, the above distribution is affected by the bolt tension and the thread geometry and material properties of both the bolt and the nut. In general, considering the stress-strain relationship for steel, as the load is increased further the first thread will reach yield and plastically deform while carrying the maximum possible load on the first thread and distributing the remaining load over a few more threads. With further increasing load, the above process will continue over the full engaged-thread length until all the threads yield and subsequently fail. However, a bolted joint should be designed to always force the failure in the bolt shank and not in the thread and therefore, if designed properly, this type of thread stripping should not occur.

The above findings also suggest that a larger number of engaged threads (fine pitch) will improve the performance of the joint as the stresses are distributed over a larger area reducing the resulting local stress concentrations.

4. CONCLUSION

The suitability of a coarse or fine thread for a particular application has to be determined on a case by case basis. In general, both coarse and fine threads are capable of providing sufficient strength for most applications. Coarse threads are easier to assemble and need less care. Hence they are more commonly used. Fine threads will, in general, have higher load carrying capacities. Fine threads are less tolerant to damage and are easily cross-threaded and therefore require careful assembly.

5. REFERENCES

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