~Fastener Expert 101~

Methods to Improve Thread Fatigue Strength – Reasons for Using Slender Bolts

by Fukuoka Toshimichi

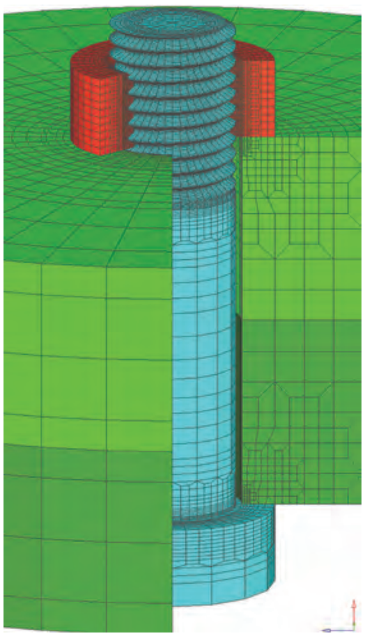


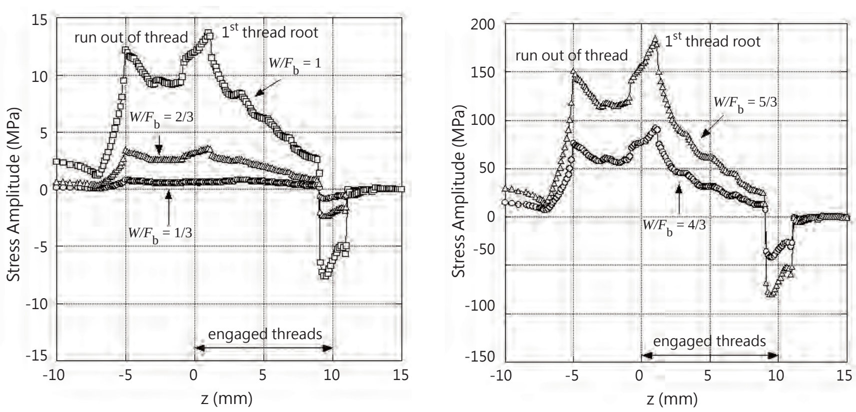
Figure. 1

1. Introduction

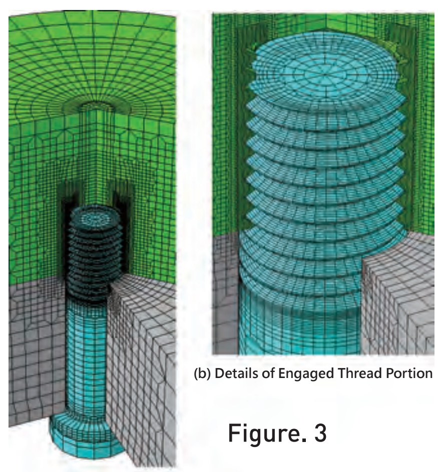
Compared to round bars and other components with simple shapes used in material tests, the phenomenon of thread fatigue failure is much more complicated. Why does the fatigue failure occur from the bolt thread root near the bearing surface of nut, rather than the nut thread root? On the other hand, in the bolted joints with mechanically machined female threads, cracks sometimes initiate from the inner most portion of female threads. In this article, using helical thread models, the phenomenon is elucidated by demonstrating the variations of stress amplitude along thread root. Meanwhile, various methods have been proposed for preventing the occurrence of fatigue failure. Here, I will introduce tangible and effective approaches to improve fatigue strength of bolted joints from the view points of thread fastening conditions, shape and materials of threaded components.

2. Evaluation of Stress Amplitude Along Thread Root

By conducting finite element analyses that uses helical thread models, I will obtain the distributions of stress amplitude along thread root and elucidate the relation between the position of fatigue failure occurrence and the maximum stress amplitude. The most widely used threaded component is the combination of bolt and nut. Figure 1 is a finite element model that correctly represents the helical shape of threads. For simplicity, external forces are assumed to exert as a tensile load repeatedly and symmetrically around the bolt axis. Figures 2 (a) and (b) are examples of the analytical results, showing the distributions of



(a) Partially in Contact Figure. 2 (b) After Complete Separation



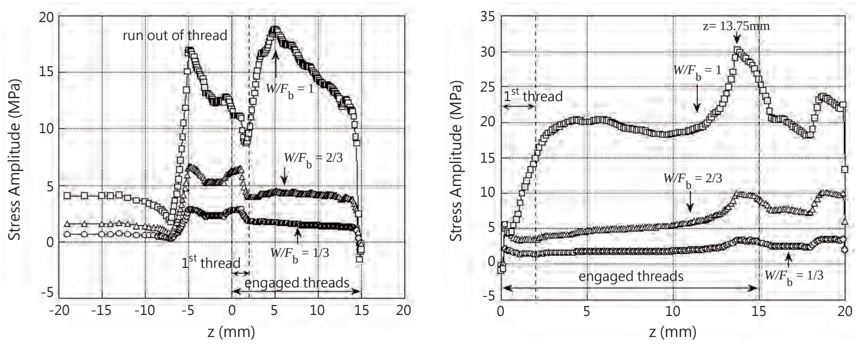
(b) Details of Engaged Thread Portion

Figure. 3

(a) FE Model of Joint Part

stress amplitude along the male thread root. The values in the figure represent the ratio of the external force W to axial bolt force Fb. Figure 2 (a) shows the contact surface of the fastened object is being partially contacted. When the aforementioned ratio exceeds 1, the stress amplitude increases significantly. In this case, the maximum stress amplitude appears at the first bolt thread root near the bearing surface of the nut. As the external force further increases, the contact surface separates completely, and then the stress amplitude increases drastically as shown in Figure 2(b). As demonstrated above, we learn that fatigue failure is likely to occur from the first bolt thread root in the bolted joint composed of a bolt and a nut.

In the case of targeted bolted joints being large, fastening operations are often conducted by machining female threads in the main body and then studs or hexagon bolts are screwed into the machined threads. In those cases, as explained in my previous article, the fatigue failure may occur from the bolt side, or cracks could initiate from the far end root of female threads in the engaged threads portion. Figure 3 is a finite element model constructed to investigate this phenomenon. The way of applying the external force is the same as the bolt-nut connection, and the analytical results are shown in Figures 4(a) and (b), which



(a) Male Thread (Bolt) Figure. 4 (b) Female Thread (Main Body)

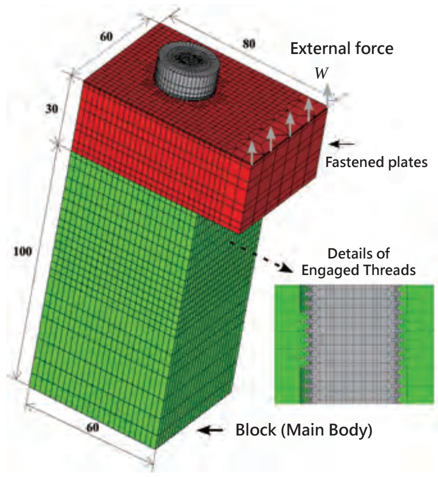


Figure. 5

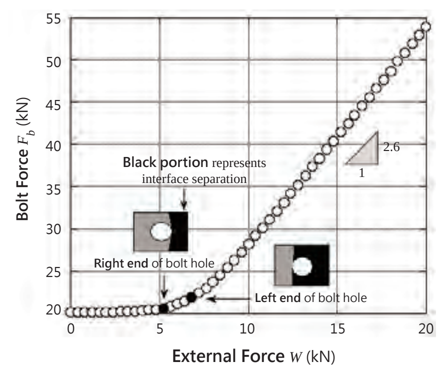


Figure. 6

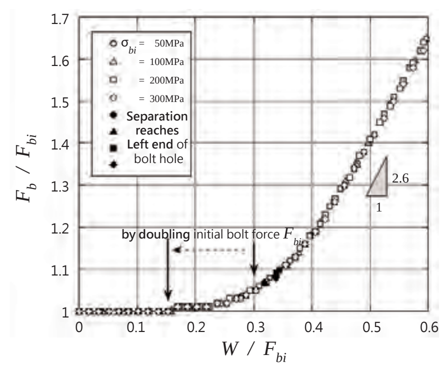


Figure. 7

respectively show the stress amplitude distributions along the bolt and the female thread root. The absolute values of the stress amplitudes are small because the contact surface is not completely separated. However, the maximum value of the female thread root is 1.5 times larger than that of the bolt thread root. In other words, the distinct peak of stress amplitude appears at the innermost female thread root. In contrast, though not shown in the figure, the absolute values of stresses along the thread root are fairly low on the female thread side. The analytical model shown in Figure 3 assumes that the whole bolted joint is composed of the same material. However, in the actual bolted joints, the material strength of the female threads is lower in most cases. As a result, bolted joints with female threads being machined in the main body are more likely to rupture from the female thread side rather than the bolt side.

3. Evaluation of Stress Amplitude of Actual Structures Subjected to Eccentric Loads

In the analyses conducted in the previous section, external forces are assumed to exert symmetrically. On the other hand, the external forces in the actual bolted joints are usually exerted asymmetrically. In those cases, as explained in my last article, a force larger than the external force may be exerted on the bolt. Here, using the bolted joint model shown in Figure 5, stress amplitudes under asymmetric external forces are calculated. Since the thread shape in the model is axi-symmetric, fatigue strength is evaluated by the “average stress amplitude of the engaged thread portion”. The external force is exerted as a bending load onto the bolt. As the external force gets larger, separation initially starts from the right end of the contact surface of the fastened objects. Then, it proceeds from the right side of the bolt hole to the left side, and eventually the separation reaches the left end of the bolt. In this state, a very large force is exerted on the bolt. Figure 6 shows an example of the analytical results. The vertical axis is for axial bolt force, and the horizontal axis is for external force. The figure shows how the surface separation progresses. When the separation reaches the left side of the bolt axis, the axial bolt force increases drastically. Figure 7 shows the results of varying initial bolt stresses, σbi. The vertical and horizontal axes respectively represent the values of axial bolt force Fb under external forces and external force W divided by initial axial bolt force Fbi. The relation between the two can almost be drawn by a single straight line, regardless of the magnitude of initial bolt force. Additionally, as shown by the arrows, if doubling the initial axial bolt force, we can significantly suppress the increase of axial bolt force, driven by the exertion of external force. Incidentally, when the external force and the initial bolt force are both doubled, although the figure is not shown here, the stress amplitude is also almost doubled. Accordingly, as the external force becomes larger, the axial bolt force needs to be increased beyond the ratio.

4. Methods for Improving Fatigue Strength

The biggest factor that affects fatigue strength is the magnitude of stress amplitude generated in the bolted joint under external forces. However, the magnitudes of external forces commonly vary depending on the performance of machinery. In this section, some strategies to enhance the fatigue strength are introduced, assuming the external forces being constant.

(1) Set the axial bolt force higher: When the external force is exerted and separation occurs, the stress amplitude increases sharply. By setting the axial bolt force higher, the occurrence of separation can be suppressed as small as possible. To accomplish this, it is effective to use high strength bolts that can apply high axial force.

(2) Use low-stiffness bolts: Figure 8 illustrates low-stiffness bolts employed for improving fatigue strength. Stiffness can be reduced by manufacturing the bolt body thinner or drilling a hole in the center for the bolts with identical nominal diameter. Consequently, since those bolts transform easily when subjected to external forces, the increase of axial bolt force can be suppressed. When using such low-stiffness bolts, the fatigue strength is improved, though the static strength reduces to some extent. In the bolted joints where metal fatigue is of great problem, low-stiffness bolts are commonly used because they usually have additional static strength. Meanwhile, hollow bolts, shown in the figure, have little effect when used for the bolted joints subjected to bending loads, due to the high stiffness against bending.

(3) Adopt bolt positions that reduce axial force variations: As we have learned from Figure 8 of my last article, when subjected to eccentric loads that are commonly encountered in actual bolted joints, by shifting the bolt position away from the fulcrum within a feasible range, the bending moment exerted on the bolt reduces and it makes it possible to suppress the stress amplitude. Figure 9 shows two tangible countermeasures.

(4) Contrivance on shapes of bolted joints: If it is difficult to change the bolt position, the above-mentioned idea can be achieved by adding protrusions to the ends of the bolted joint as illustrated in Figure 10.

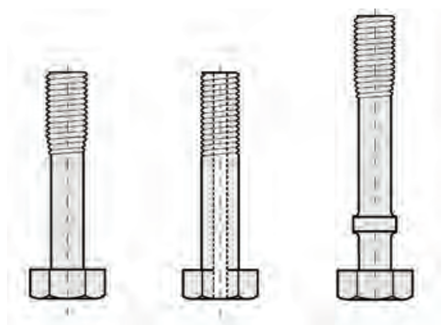
(5) Others: Materials with high static strength has high fatigue strength as well. However, the precision of thread dimension may reduce due to the difficulty involved in the manufacturing process. Particularly, when machining female threads in the main body, cutting operation is commonly used because it is difficult to process with roll forming. In those cases, the precision of the manufacturing process is lower compared to the threads of commonly used bolts and nuts. In other words, when processing female threads into high strength materials, you have to pay attention to the fact that the fatigue strength of the threaded product may not be improved, because the precision of the manufacturing process is likely to reduce even if the material has high fatigue strength.

5. Concluding Remarks

A proverb in Japan says, "Willow trees against the wind", which means that thin and flexible branches of willow trees merely sway against the incoming wind, so that large force does not exert on the branch. It is a reminder for people to quit the stubborn way of living in the human society. The intention of the proverb favorably coincides with the fact introduced in this article, i.e., slender bolts have higher fatigue strength compared to the usual bolts with identical nominal diameters. That is, it states that the variations of axial force in slender bolts are lowered because low-stiffness bolts easily deform when subjected to external forces.

Reference:

1. Toshimichi Fukuoka, "Threaded Fasteners for Engineers and Design – Solid Mechanics and Numerical Analysis –", pp.185-207, Corona Publishing Co., Ltd. (2015)



(a)Slender Bolt (b)Hollow Bolt (c)Crank Pin Bolt

Figure. 8

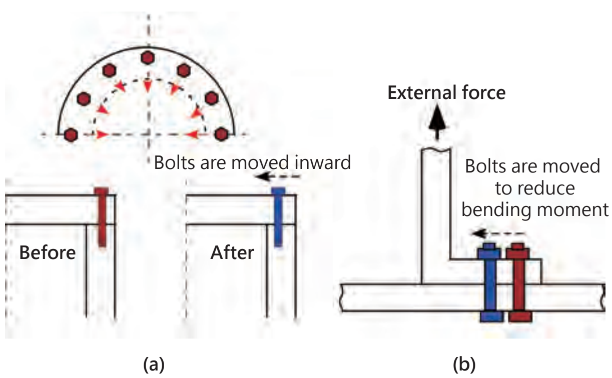


Figure. 9

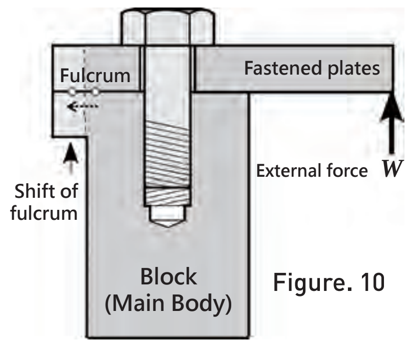


Figure. 10