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Optimum Dimensions of Thin Walled Tube on the Mechanical Performance of Super Stud Bolt

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Abstract. The bolts and nuts are widely used in various fields as important joining elements with long history. However, loosening induced by the vibration and external loads is still a big problem. And the loosening sometimes causes very serious accident without notice. This paper deals with a special stud bolt named "Super Stud Bolt (SSB)" which can prevent loosening effectively. There is a thin walled tube between the upper and lower threads, which can be deformed along the axial direction so that the phase difference is produced and SSB is developed. This phase difference induces the contrary force on the surfaces of the upper and lower threads, which brings out the anti-loosening performance. In this study, the processing and fastening-loosening courses are simulated with the finite element method. And the anti-loosening performance is analyzed and realized. In addition, the anti-loosening performances under various phase differences are compared and finally best dimensions for SSB are examined.

Introduction

Threaded connections play a critical role in engineering with long history. Because of their relatively low cost and easy disassembly for maintenance, they are widely used for mechanical products and structures in modern times. However, self-loosening, which is one of the most frequent failure modes for threaded connections, brings out the failure of engineering products and several serious accidents. Therefore, in recent years much attention has been paid to the research on the anti-loosening. Many experiments have been performed in order to find out the reasons and the influence factors of self-loosening. Moreover, Finite Element Method (FEM) is widely used on these types of research (1, 2) with the recent development of the computer. Based on these, all kinds of anti-loosening nuts are invented[3-4]. And some stud bolts are also produced for anti-loosening, for example, shaft end plates (wire type) and bent plates shown in Fig. 1. However, these kinds of anti-loosening bolt can not be used repeatly, dismentling is difficulty and component is complex.

In order to make up these fault, the super stud bolt is developed as shown in Fig. 2 (a). This kind bolt can prevent loosening easily. In this anti-loosening mechanism, the thin walled tube between the upper threads and the lower threads plays an important role as shown in Fig.2 (b). The thin walled tube can be deformed along the axis, and the phase difference of lower and upper threads is designed in the course of processing. Accordingly, the deformation must be produced in order that the threads meet each other in the course of fastening. Then, the thread contact force shown in Fig. 2 (b) comes out due to this deformation. This force is called the griping force, by which the prevailing torque is produced, so that the self-loosening can be prevented. This is the working principle of the Super Stud Bold (SSB).

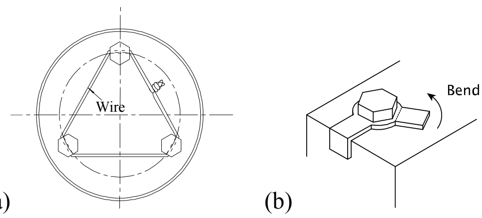
Since the thin walled tube is the heart of anti-loosening mechanism, the best original dimensions will be discussed in this study. Moreover, in this paper the M16 SSB is taken as a sample, and the capability of the anti-loosening will be investigated using FEM. Both courses of processing and fastening will be simulated, and the relation between axial force and displacement will be researched. Incording to the results, the best original dimensions will be decided.

Analysis model and method

Analysis model. In Fig.3 (a), the SLN is simplified into an axi-symmetric model to be studied. Here the bottom is fixed, while the forced displacement z (mm) is placed on the top of the model by the rigid body. In this study, the thin walled tube is mainly researched with the finite element method as shown in Fig.3 (b).

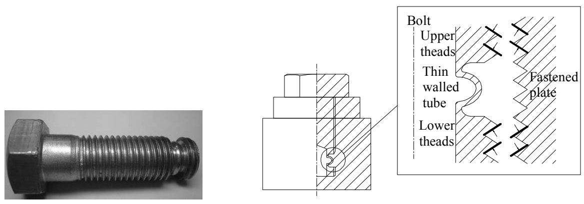
The material of the SSB is SC435 (JIS), whose stress-strain relation in Fig.4 is used in the elastic-plastic finite element analysis of the thin walled tube. Here, Young's modulus is 210GPa, Poison's ratio is 0.3, and the yielding stress is 800MPa.

Analysis model. With the axi-symmetric FE model, both courses of processing and fastening-loosening of SSB are simulated. The processing course is shown in Fig. 5, and the course of fastening-loosening is shown in Fig.6. In the Fig. 5 (a), the length L of thin walled tube is produced on the top of normal bolt by machining. At this time, the phase difference of lower and upper threads is 0. As shown in Fig. 5 (b), the thin walled tube is pressed by (p-α) mm. Here, α (mm) is the nominal phase difference of lower and upper threads, which is smaller than the pitch of nut (p=2mm). When the press is removed, spring back happens as shown in Fig. 5 (c). Here, L_1=L-(p-α) and L_2=L-(p-α)+b, so that the real phase difference of lower and upper threads α_2=α+b=p-(L-L_2) appears. Figure 6 (d) is the same as Fig. 5 (c), and Fig. 6 (e) shows the phase difference of lower and upper threads becomes 0 because the threads of the bolt and nut can meet each other while the nut is fastened. In Fig. 6 (f), spring back b′ happens after loosening. In order to simulate both courses which include large plastic strains, elastic-plastic large deformation theory will be applied in this analysis.



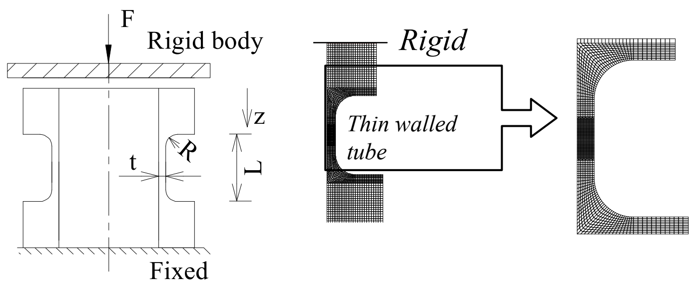
(a) (b)

Fig.1 Anti-Loosening stud bolts previously proposed



(a) Photo (b) Anti-loosening theory

Fig.2 Super stud bolt recently proposed



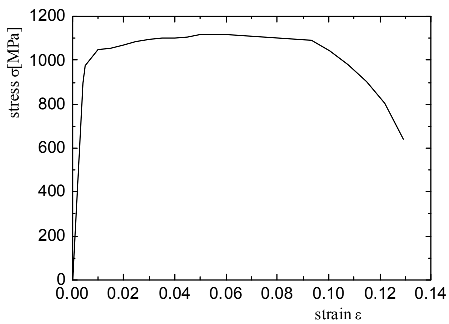


Fig.3 (a) Analysis model (b) Finite element model (c) Detail of thin walled tube Fig.4 Relation between stress and strain for SCM435

Analysis results

The anti-loosening capability A standard model M16 bolt is employed, and the dimension of the thin walled tube is shown in Fig.3(a), here, L=5.8mm, R=1mm and t=0.6mm.

In order to design the phase difference of lower and upper threads (α=0.1mm), the relation between the axial force and the displacement is shown in Fig.7. The course of processing is indicated as the line (a) → (b) →(c); then, the final displacement 1.84mm provides the real phase difference of lower and upper threads 0.16mm. The line from (d) to (e) shows the course of fastening, and the line from (e) to (f) shows the course of loosening. In those loading and unloading courses, the plastic deformation occurs and the permanent deformation 1.94-1.84=0.1mm has been added. Then, only small phase difference of lower and upper threads (2.00-1.94=0.06mm) remains. However, in consecutive fastening-loosening courses, the relation between the axial force and the displacement moves to the line from (f) to (e). Because the deformation in this course is totally elastic, plastic deformation does not occur and the phase difference of lower and upper threads 0.06mm will not be changed anymore. Moreover, the axial force 14.51kN is also unchanging, and therefore, the prevailing torque is the same in the consecutive fastening-loosening courses.

From Fig. 7, it can be shown when the threads meet each other (Fig. 7(e)), the axial force is 14.51kN. Accordingly, the prevailing torque may be evaluated as Ts=20.64 N·m by Eq.(1)[5].

$$T = \frac{d_2}{2} F \tan\rho' + \frac{d_2}{2} F \tan\beta + \frac{d_w}{2}\mu_w F \qquad (1)$$

Where F is axial force,
d is the radius of screw, and approximately d_2 =0.92 d, d_w=1.3 d_2,
ρ' is friction angle between the threads, here tan(ρ')=0.15
β is lead angle of threads, 2.4796 (deg)
μ_w is average friction factor on the interface between the head of bolt and the clamp.

Influence of the dimension of the thin walled tube on the anti-loosening capability The thin walled tube is the heart of SSB because the dimension has large influence on the anti-loosening capability, stress distribution and spring factor. In this study, the inference of the dimensions *R, L, t* in Fig. 3 will be investigated, and best dimensions will be examined.

(a) Influence of curvature radius *R* In order to improve stress distribution at both ends of thin walled tube, the effect of curvature radius *R* in Fig. 3(a) is studied. As shown in Fig. 3(a), *L* and *t* are fixed as *L*=6.0mm, *t*=0.65mm, and *R* is changed. When *R* is 0.0, 0.5, 1.0, the stress distributions of the thin walled tube in Fig. 5 (b) are shown in Fig.9 (a), (b), (c), respectively.

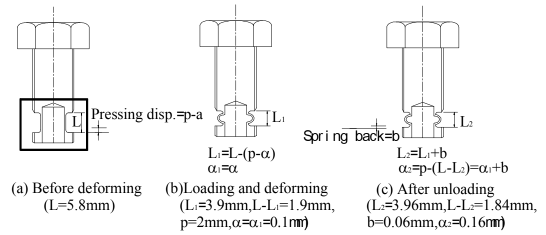


Fig.5 Dimension change in the course of processing [( ): Values in Fig. 7]

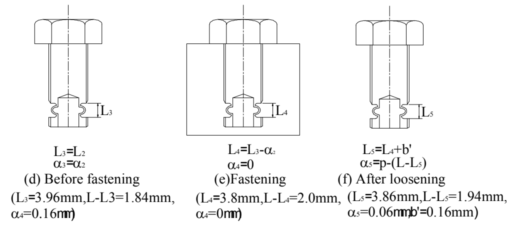
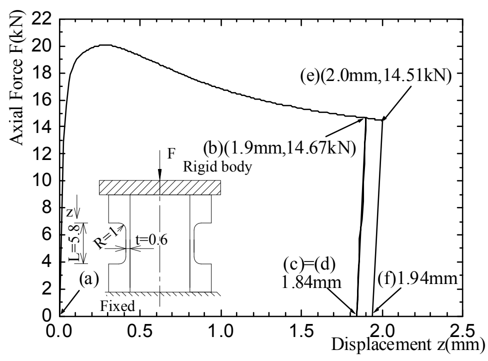
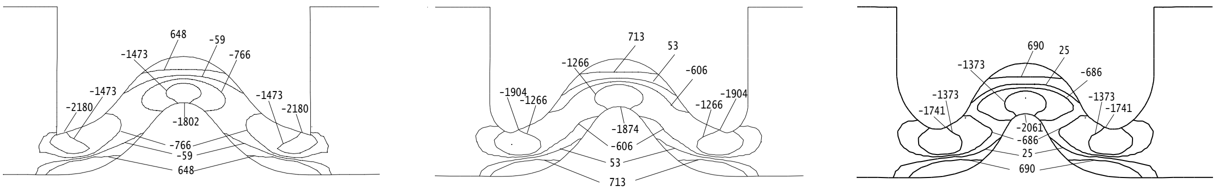


Fig.6 Dimension change in the course of fastening [( ): Values in Fig. 7]



(a) → (c) Processing
(d) → (e) Fastening
(e) → (f) Loosening
(f) → (e) Fastening from second time
(e) → (f) Loosening from second time

Fig.8 Relation between axial force and displacement (L=5.8mm,R=1mm,t=0.6mm)

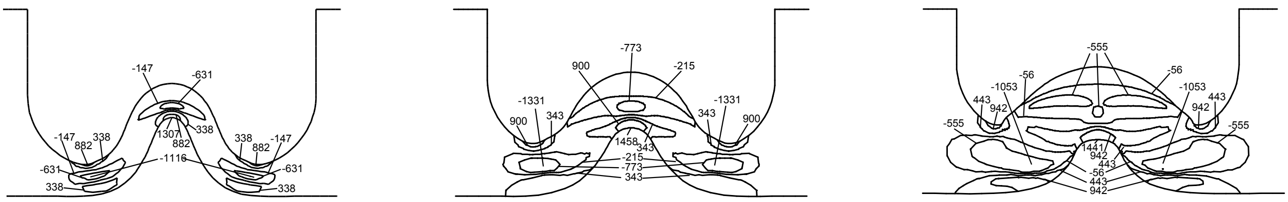


(a) R=0mm (b)R=0.5mm (c) R=1.0mm

Fig.9 Stress distribution σ_z (MPa) for different curvature R (L=5.8mm, t=0.6mm, α_l=0.1mm)

Table.1 Effect of initial length of thin tube L
(L-L_1=1.9mm in Fig.5, R=1.0mm, t=0.6mm in Fig.3(a))

Length of thin walled tube L (mm)	Spring factor k ($\times10^8$N/m)	Spring back (Elastic deformation) b(mm)	Prevailing torque Ts(N-m)
4.8	4.36	0.04	25.08
5	3.88	0.04	23.86
5.8	2.63	0.06	20.64
6	2.42	0.06	19.83
6.8	1.89	0.07	17.73



(a) t=0.4mm (b) t=0.6mm (c) t=0.8mm

Fig.10 Distribution of σ_z(MPa) (R=1.0mm, L=5.8mm)

From Fig.9, while R is smaller, the stress concentration is more serious at both ends of the thin walled tube. Conversely, while R is larger, at the center of the thin walled tube the stress become larger. The stress distribution is the most desirable in Fig. 9 (b) while R is 0.5mm.

(b) Influence of Length of Thin Walled Tube *L* To investigate the effect of length L, dimensions R and t are fixed as R=0.5mm, t=0.65mm, and L is changed (see Fig. 3(a)). When L is 5.0, 6.0, 8.0, the results are shown in Table 1.

From Table 1, while L is longer, the spring factor becomes smaller, and spring back b in Fig. 5 becomes larger. Here, spring back b may be regarded as an amount of elastic deformation. It should be noted that this elastic deformation is much smaller than the phase difference of lower and upper threads (0.1~0.15mm). In other words, large plastic deformation always exists in the course of first fastening-loosening whenever L is 5, 6 or 8mm. It can be seen that the prevailing torque becomes smaller while L is longer in Table 1. That is to say, the anti-loosening capability becomes lower as L is longer. In addition, the cost of processing is higher when L becomes longer. According to the above, the length of thin walled tube should be designed as short as possible if the thin walled tube can be deformed as shown in Fig. 3(a). It may be concluded that L=5mm is the best.

(c) Influence of Thickness of Thin Walled Tube *t* In order to improve both processing and fastening courses, the influence of the thickness of the thin walled tube t is studied. While the L and R are fixed, thickness t is changed as 0.4, 0.6, and 0.8mm. The stress distributions σ_z are indicated in Fig. 10 (a), (b) and (c).From Fig.10, it is seen that the stress distribution becomes complicated with increasing the thickness t. The stress distribution of t=0.4mm is desirable, and therefore, it may be concluded that the best thickness t is 0.4mm.

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