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FATIGUE STRENGTH EVALUATION FOR BOLT-NUT CONNECTIONS HAVING SLIGHT PITCH DIFFERENCE CONSIDERING INCOMPLETE THREADS OF NUT

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Abstract: The high strength bolts and nuts are widely used in various fields. In this study the effect of slight pitch difference is considered when the nut pitch is *α* μm larger than the bolt pitch. In the first place, the fatigue experiment is conducted with varying pitch difference. The results show that the fatigue life is extended to about 1.5 times by introducing the suitable pitch difference under the high stress amplitude. Next, the detail observation is performed on the fractured specimens including the fractured positions and the crack configurations. It is found that the fractured positions and the crack distributions vary depending on the pitch difference. Finally, to clarify the improvement mechanism of the fatigue strength, the finite element method is applied to calculate the stress amplitude and mean stress at each bolt threads, and the incomplete threads at the nut ends are also considered to obtain the accurate analytical results.

Keywords: Bolt-Nut connections, Pitch Difference, Fatigue Life, Finite Element Analysis

1 INTRODUCTION

Bolt-nut connections are commonly used in engineering structures due to the advantages they offer, such as the ability of clamping, and the ease of disassembly for maintenance or repair. However, fatigue failure problems of bolt are always of concern. High stress concentration factors always occur at the root of bolt thread and it is not easy to improve the fatigue strength of screws. Most previous studies are focusing on the anti-loosening performance for newly developed bolt and nut [1-3].

The effect of the thread shape on the fatigue life of bolt has been investigated [4-6]. A previous study indicated that the fatigue strength may be improved depending on the pitch error [7]. Our previous experiment clarified that the fatigue life is improved by introducing suitable pitch difference under a certain level of stress amplitude [8].

As further work, in the present study, two types of specimens will be investigated systematically, including the standard bolt-nut connections and the connections having a slight pitch difference *α*. Figure 1 shows the schematic diagram of bolt and nut connection. First, the fatigue experiment will be carried out for the two types of specimens with varying stress amplitude systematically. Afterwards, the fractured specimens will be investigated. Finally, to clarify the improvement mechanism of the fatigue strength, the finite element analysis will be applied to calculate the stress amplitude and mean stress at each bolt threads. In order to obtain the accurate analytical results, the longitudinal section of nut specimen was investigated as shown in Fig. 2. It's noticeable the incomplete end threads may have an effect on the contact status between bolt and nut, therefore, we will pay attention to the incomplete threads of nut in the FE analysis.

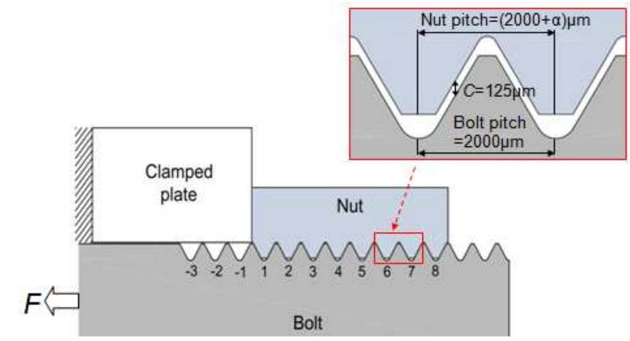


Fig. 1 Schematic diagram of bolt-nut connection

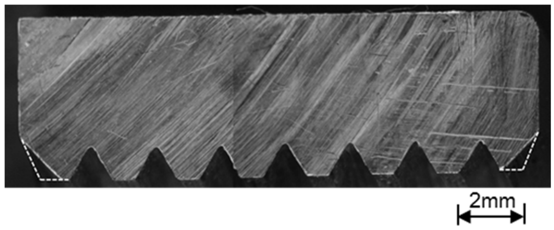


Fig. 2 Incomplete threads at nut ends

2 EXPERIMENTAL SET-UP

2.1 Materials

In this study, the Japanese Industrial Standard (JIS) M16 bolts and nuts are employed. The strength grade of bolt and nut is 8.8 and 8, respectively. Table 1 presents the material property of bolt and nut. The standard M16 bolt and nut have the same pitch dimension as 2000 μm. Herein, the nut pitch is assumed to be (2000+α) μm, and α is named as pitch difference. Motivated by the results of previous study, two types of pitch differences, i.e. α=0 (standard bolt nut connection) and $\alpha=\alpha_m$ are considered in this study. The clearance between bolt and nut has a standard dimension as 125 μm as shown in Fig. 1.

Table 1 Material Property of Bolt and Nut

	Young's modulus (GPa)	Poison's ratio	Yield strength (MPa)	Tensile strength (MPa)
SCM435 (Bolt)	206	0.3	800	1200
S45C (Nut)	206	0.3	530	980

2.2 Fatigue tests

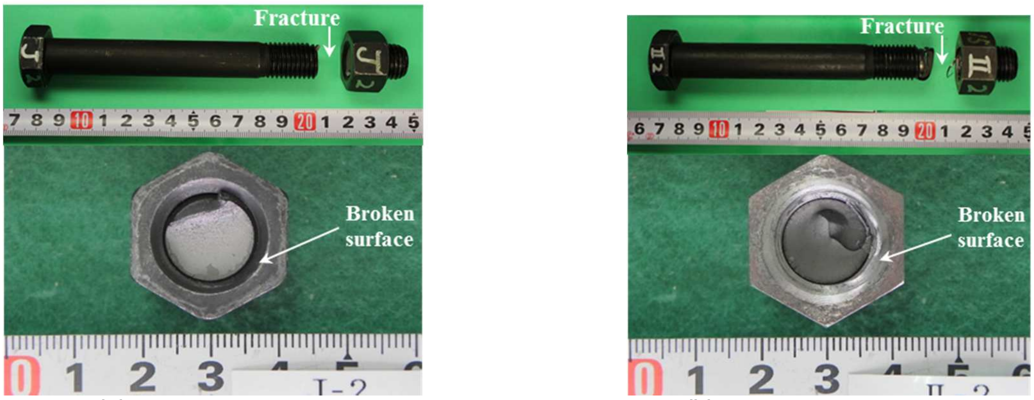
The fatigue experiment is conducted by using 392 kN Servo Fatigue Testing Machine. A series cyclic loading were applied to the specimens. Table 2 summarizes the experimental loading conditions and the corresponding stress with considering the bottom cross sectional area of bolt as A_R=141 mm^2. The cycling frequency of the loadings is 8 Hz.

2.3 Experimental Results

Figure 3 shows the fractured specimens which underwent a stress amplitude of σ_a=100 MPa. For the standard bolt-nut connection, it is confirmed that the fracture always occurs at the bottom of thread No.1. For the specimens of $\alpha=\alpha_m$, the fracture takes place nearby No.1 thread, and the fracture surface shows noticeably different characteristics.

Table 2 Experimental loading conditions

Load (kN)		Stress (MPa)	
Mean load	Load amplitude	Mean stress	Stress amplitude
30	22.6	213	160
30	18.3	213	130
30	14.1	213	100
30	11.3	213	80
30	8.5	213	60
30	7.1	213	50



(a) $\alpha=0$, σ_a=100MPa (b) $\alpha=\alpha_m$, σ_a=100MPa

Fig. 3 Fractured specimens

The S-N curves with fatigue limit at $N=2\times10^6$ stress cycles are obtained as depicted in Fig.4. It is found that the pitch differences effects the fatigue life significantly. When the stress amplitude is above 80 MPa, the fatigue life for $\alpha=\alpha_m$ is about 1.5 times of the standard bolt-nut connections ($\alpha=0$). However, near the fatigue limit, the fatigue lives of the two types of specimens are similar, and the fatigue limits remain at the same value of 60 MPa.

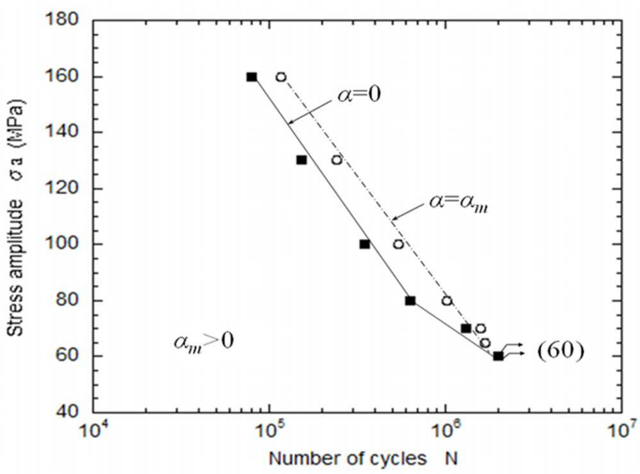
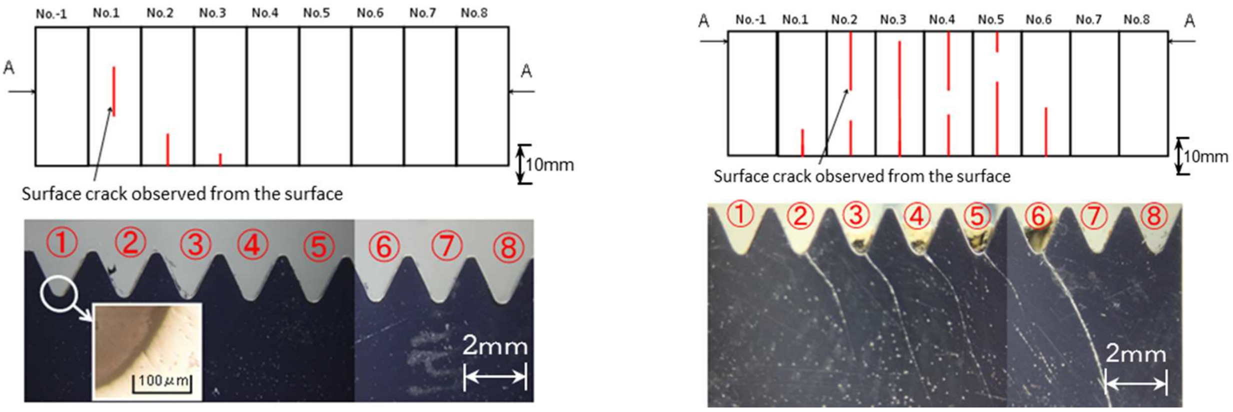


Fig. 4 S-N curves

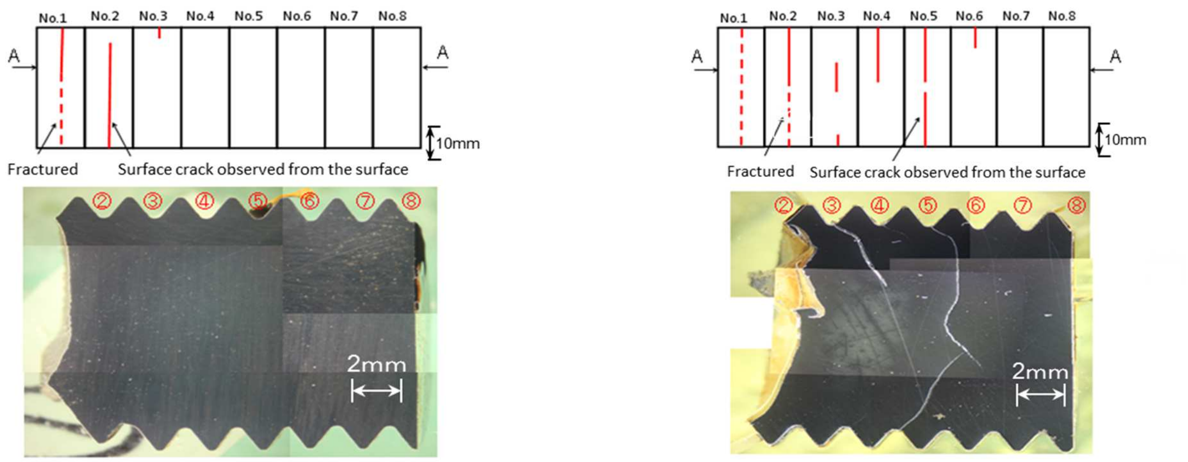
3 CRACK OBSERVATION

Figure 5 and Figure 6 show the observed trajectory of cracks along the longitudinal cross section of the specimens at the fatigue stress amplitudes σ_a=60 MPa and 100 MPa. For the standard bolt-nut connections, it can be seen that the initial crack may occur at thread No.2, and final fracture happens at No.1 thread. For $\alpha=\alpha_m$, the initial crack may start at No.5 thread or No.6 thread, extending toward thread No.1 and finally fracture happen nearby thread No.1. From the S-N curves and the observations of crack trajectories, we can conclude that the fatigue life of the bolt-nut connections may be extended by introducing a pitch difference because the changes in crack propagation trajectory may take place.



(a) α=0 (b) $\alpha=\alpha_m$

Fig. 5 Crack configuration observed from the surface and at the longitudinal section of the bolt when σ_a=60MPa



(a) α=0 (b) $\alpha=\alpha_m$

Fig. 6 Crack configuration observed from the surface and at the longitudinal section of the bolt when σ_a=100MPa

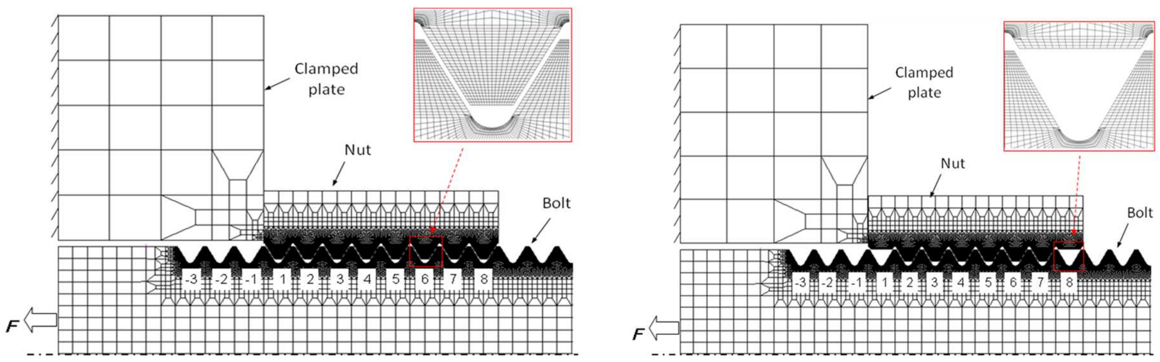
4 FINITE ELEMENT ANALYSIS

To analyse the stress at the bolt threads, the axisymmetric model of the bolt-nut connection is created by using FEM code MSC.Marc/Mentat 2012. The elastic-plastic FE analysis is performed. The multifrontal sparse solver is used. Friction coefficient of 0.3 is entered in contact table and Coulomb friction is used.

Considering the incomplete threads of nut shown in Fig. 2, here, the complete thread model and the incomplete thread model are created as shown in Fig. 7. In accordance with the experimental specimens, two types of pitch differences, i.e. α=0 and $\alpha=\alpha_m$ are analysed by using both the complete thread model and incomplete thread model. At the roots of bolt threads a very fine mesh with a minimum size of 0.01mm is used. The clamped plate is fixed in the horizontal direction and the bolt head is subjected to cyclic load F. For each bolt thread from No.-2 thread to No.8 thread, the maximum stress amplitude and the mean stress are investigated at the point where the maximum stress amplitude appears. According to these stress components, the endurance limit diagrams are obtained to evaluate the relative danger level of the bolt threads. Figure 8 shows the endurance limit diagrams analysed by using the complete thread model when the load F=30±14.1kN. In the endurance limit diagram, the Soderberg line is plotted. It should be noted that because of the stress gradient, the maximum stress amplitude for fracture of notched specimens is always larger than that of the plain specimens. Therefore, the stress data plotted beyond the Soderberg line does not represent the real fracture at the bolt thread.

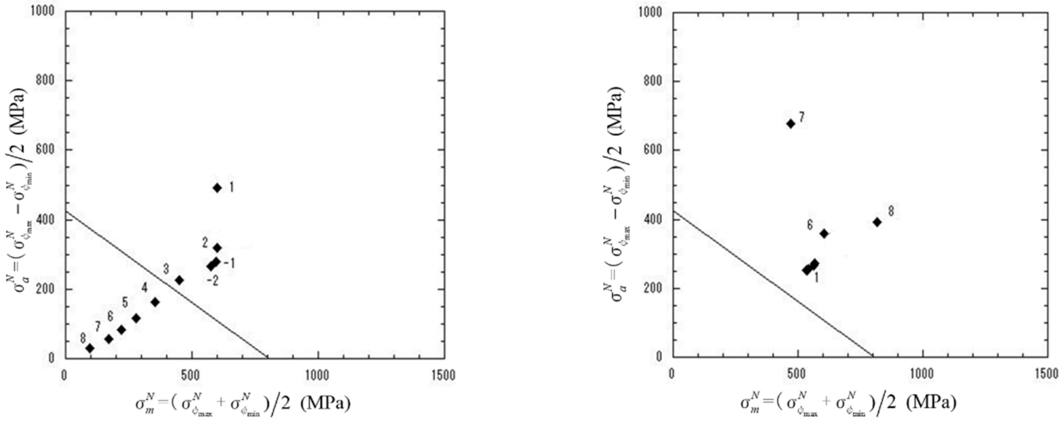
For α=0, Fig. 8 (a) indicates that thread No.1 has the highest stress amplitude. On the other hand, for $\alpha=\alpha_m$, Fig. 8 (b) shows that No.7 and No.8 thread become more dangerous. However, these analytical results do not correspond to the crack observation results very well, because the crack may initiate at No.2 thread for α=0, and large crack occurs at No.5 thread for $\alpha=\alpha_m$ when σ_a=100 MPa as illustrated in section 3.

Figure 9 shows the endurance limit diagrams analysed by using the incomplete thread model. For α=0, thread No.2 becomes the most dangerous thread in accordance with the observed crack. For $\alpha=\alpha_m$, the stress amplitude at No.6 thread increases while that at No.7 thread decreases, and these results become more closer to the crack configuration in Fig.6 (b) where the large crack occurs at No.5 thread.



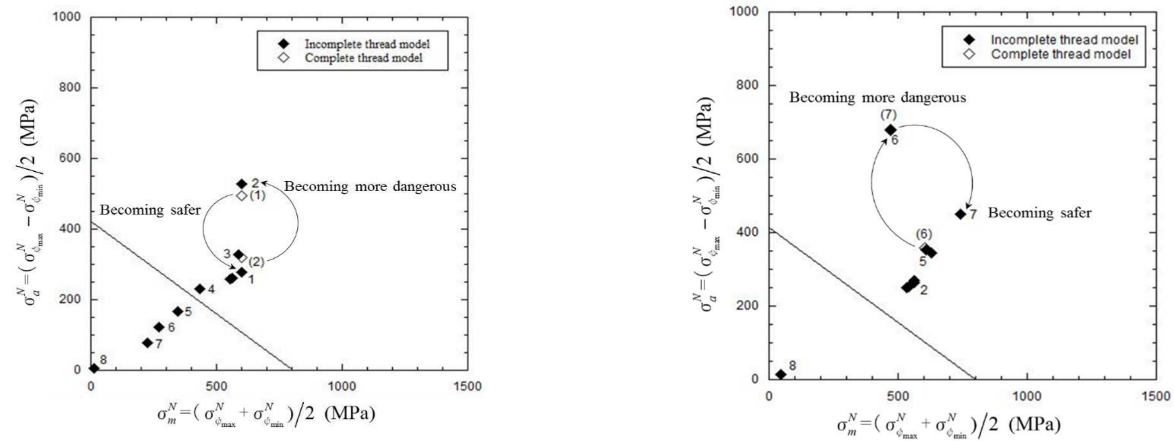
(a) Complete thread model (b) Incomplete thread model

Fig. 7 Axi-symmetric finite element model of bolt-nut connection



(a) α=0 (b) α=α_m

Fig. 8 Endurance limit diagram, σ_a=100MPa (Complete thread model)



(a) α=0 (b) α=α_m

Fig. 9 Endurance limit diagram, σ_a=100MPa (Complete thread model vs Incomplete thread model)

5 CONCLUSIONS

A slight pitch difference α is considered between the M16 bolt-nut connections. The fatigue experiment has been conducted for two types of pitch difference, i.e. α=0 and α=α_m. The stress amplitude and mean stress at each bolt threads have been numerically analysed using the finite element method with considering the incomplete threads of nut. The conclusions can be summarized as follows:

(1) For α=0, the incomplete thread model explains that the crack initiates at No.2 thread as shown in Fig. 9 (a).

(2) For α=α_m, the incomplete thread model explains the crack initiates at No.5 or No.6 threads as shown in Fig. 9 (b).

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