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EXPERIMENTAL INVESTIGATION ON THE SUITABLE PITCH DIFFERENCE IMPROVING THE FATIGUE STRENGTH SIGNIFICANTLY FOR HIGH STRENGTH BOLTS AND NUTS

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Abstract: The high strength bolts and nuts are widely used in various fields. To ensure the structure safety, a lot of special bolts and nuts were studied previously. In this paper, a slight pitch difference is considered between the bolt and nut. Here, the pitch of the nut is α μm larger than the pitch of the bolt. The fatigue experiment is performed for three kinds of specimens with different levels of pitch difference. The obtained S-N curves show that the fatigue life is extended by about 1.5 times by introducing the suitable pitch difference especially under the high stress amplitude. According to the detail investigation on the fractured specimens, it is found that the fractured positions and the crack configuration are totally different by introducing the pitch difference. To find out the mechanism of the improvement of the fatigue strength, the finite element method is also applied to calculate the stress amplitude and mean stress at each bottom of bolt threads.

Keywords: bolted joint; pitch difference; fatigue strength; crack; finite element method

1 INTRODUCTION

The bolts and nuts are important joining elements widely used in various engineering fields. To ensure the structure safety, the high fatigue strength has been required as well as the anti-loosening performance. However, because high stress concentration factors always occur at the root of bolt thread and it is not easy to improve the fatigue strength for normal bolt and nut. A previous study indicated that the fatigue strength may be improved depending on the pitch error [1]. The effect of the thread shape on the fatigue life of bolt has also been investigated [2]. The tapered bolts named CD bolts (Critical Design for Fracture) are widely used because they showed higher fatigue strength experimentally [3,4]. Hua Zhao analyzed the stress concentration factors within bolt-nut connectors [5].

In this study, in order to improve the fatigue strength, a slight pitch difference is considered between the bolt and nut. The authors' previous study shows that the pitch difference improves the bolt fatigue life [6]. In this paper, more detailed fatigue experiment is conducted systematically under various stress amplitudes for three types specimens having different pitch difference. Then the S-N curves and fatigue life will be discussed under these conditions. To clarify the effect of pitch difference, the finite element method will be applied to analyze the stress amplitude and mean stress at the thread bottoms. The fatigue life improvement mechanism will be considered by comparing the experimental results and the finite element analysis.

2 RESEARCH METHOD

2.1 Experimental Materials

The Japanese Industrial Standard (JIS) M16 bolts and nuts are employed, and the fatigue experiment is conducted by using the 392kN Servo Fatigue Testing Machine. Table 1 and Table 2 show the JIS standard and the material properties of the bolt and nut. The normal M16 bolt and nut have the same pitch dimension 2000μm, here, the nut pitch is assumed to be equal or slightly larger than the bolt pitch. Three types of pitch difference α=0, α=15μm and α=33μm are considered. The clearance between bolt and nut is assumed as a standard dimension 125μm. The schematic diagram of bolt and nut is shown as Fig. 1. Figure 2 shows the contact status between bolt and nut when a large pitch difference is introduced.

Table 1 JIS Standard of Bolt and Nut

	Strength grade	Yield strength (MPa)	Tensile strength (MPa)
Bolt	8.8	660	830
Nut	8	-	-

Table 2 Material Properties 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

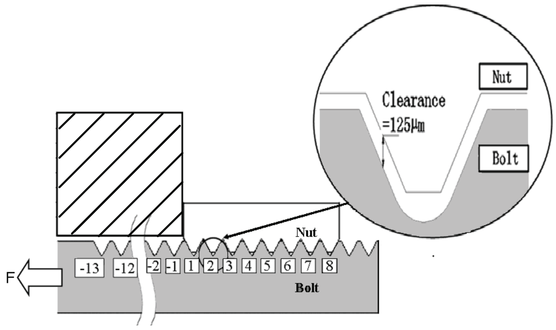

Fig. 1 Schematic diagram of bolt joint

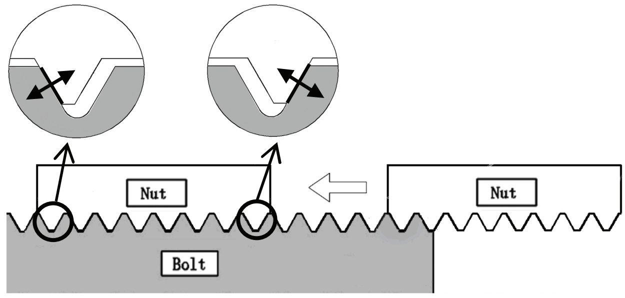

Fig. 2 Contact status between bolt and nut considering pitch difference

2.2 Experimental Conditions

The experimental device is shown in Fig.3. The bolt specimens are subjected to a series repeated loadings. Table 3 shows the experimental loading conditions and the corresponding stress according to the bottom cross sectional area of the bolt A_R=141 mm^2. The cycling frequency of the loadings is 8Hz. The stress amplitude that the specimen sustains 2×10^6 stress cycles before failure occurs is considered as the fatigue limit.

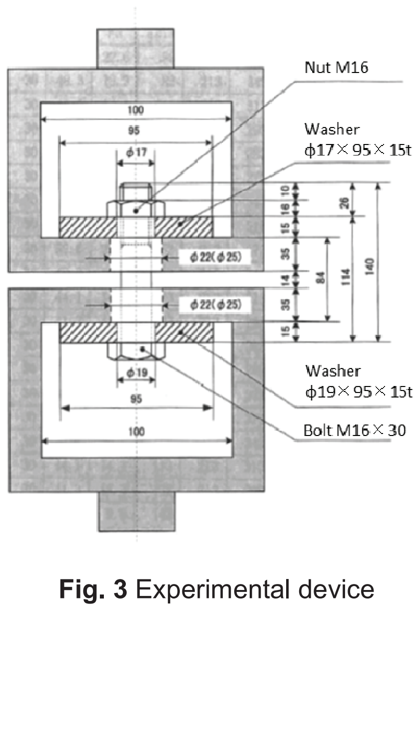

Fig. 3 Experimental device

Table 3 Experimental 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

3 THE FATIGUE EXPERIMENT RESULTS

Figures 4 to 6 show the fractured specimens subjected the stress amplitude σ_a=100MPa. For the normal bolts and nuts, it is confirmed that the fracture always occurs at the first thread bottom as shown in Fig.4. For the specimens of α=15μm and α=33μm, the fracture position is between the No.1 thread and No.3 thread of bolt. The fracture surfaces also show obviously different characteristics as varying the pitch difference.

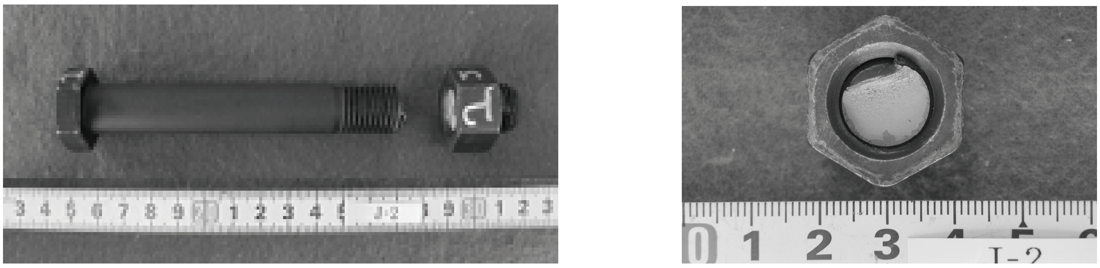

Fig. 4 Specimen (α=0 μm, σ_a=100 MPa)

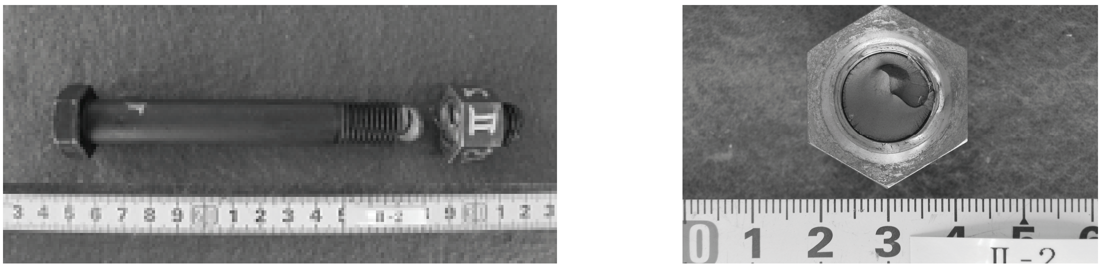

Fig. 5 Specimen (α=15 μm, σ_a=100 MPa)

Fig. 6 Specimen (α=33 μm, σ_a=100 MPa)

The S-N curves with fatigue limit at $N=2\times10^6$ stress cycles are obtained as shown in Fig. 7. It is found that the fatigue lives are clearly different depending on the three levels of pitch difference. Table 4 shows the comparison between the fatigue life normalized by the results of α=0. When the stress amplitude is above 80 MPa, the fatigue life for α=15μm is about 1.5 times larger and the fatigue life for α=33μm is about 1.2 times larger than the normal bolt and nut of α=0. However, near the fatigue limit, the fatigue life of three types specimens is not very different, and the fatigue limit remains the same value of 60 MPa for three cases of pitch difference.

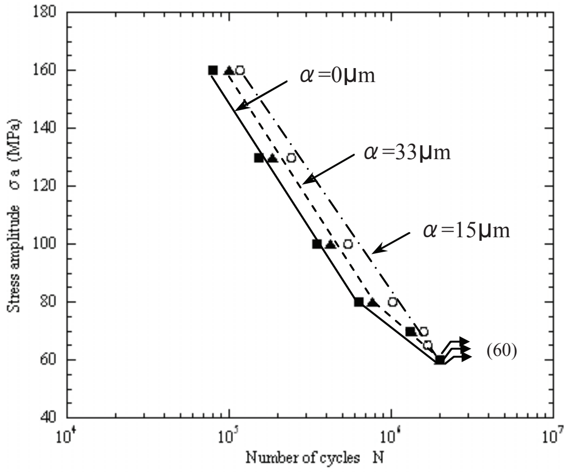

Fig. 7 S-N curves

Table 4 Comparison between the fatigue life

Pitch difference	Stress amplitude σ_a (MPa)				
	160	130	100	80	70
α=0μm	1	1	1	1	1
α=15μm	1.49	1.60	1.53	1.61	1.21
α=33μm	1.26	1.22	1.20	1.21	1.02

4 THE CRACK OBSERVATION

Figures 8-10 show the observed cracks distribution with the longitudinal cross section of the specimens under the stress amplitude σ_a=100MPa. For the specimen α=0μm, there is no crack observed. For the specimen α=15μm, a large crack occurs at No.5 thread with also small cracks between No.5 thread and No.2 thread where the fracture occurs. For the specimen α=33μm, a large crack occurs at No.6 thread with small cracks between No.6 thread and No.1 thread where the fracture occurs.

Crack observation in Fig.8 shows that for the normal bolt and nut, the crack occurs at No.1 thread causing finial fracture. However, for the specimens α=15μm and α=33μm in Fig.9, 10, the initial crack starts at No.5 thread or No.6 thread extending toward No.1 thread and finally fracture happens nearby No.1 thread. Therefore, the fatigue life of the bolt may be extended by introducing the pitch difference.

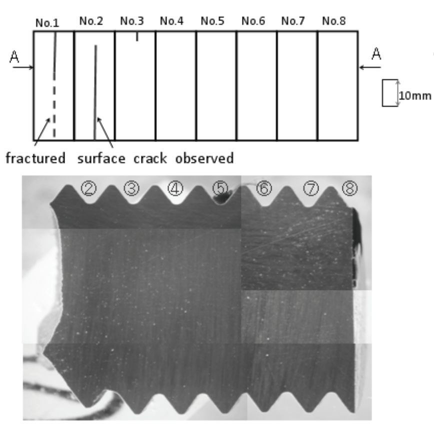

Fig. 8 Crack observation

(α=0 μm, σ_a=100 MPa)

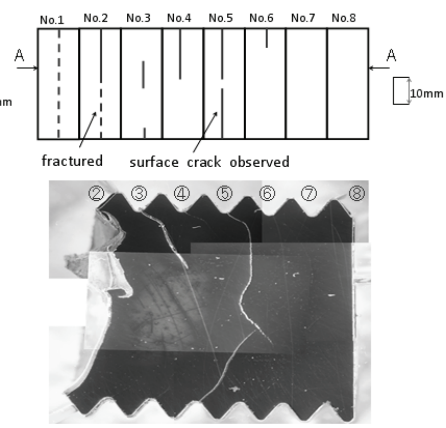

Fig. 9 Crack observation

(α=15 μm, σ_a=100 MPa)

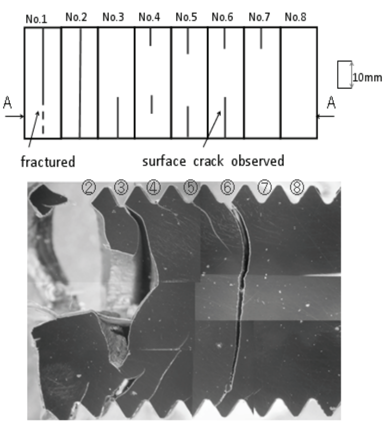

Fig. 10 Crack observation

(α=33 μm, σ_a=100 MPa)

5 THE FINITE ELEMENT ANALYSIS

To analyze the stress status at the bottom of the bolt threads, the finite element models are created by using FEM code MSC.Marc/Mentat 2007. Three models have the different pitch difference of α=0, α=15μm and α=33μm in according with the experimental specimens. Figure 11 shows the axisymmetric model of the bolt, nut and clamped plate. The elastic-plastic analysis is performed for three models under the same load F=30±14.1kN. The material properties listed in Table 2 are used in the calculation. For each thread bottom from No.-3 to No.8, the stress status where the maximum stress amplitude occurs is considered, and the mean stress and the stress amplitude at that node are calculated to obtain the endurance limit diagrams as shown in Fig.12-14. The fatigue limit σ_N of the material SCM435 is 420 MPa.

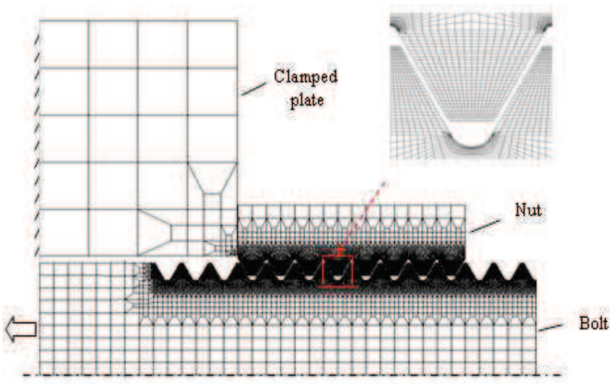

Fig. 11 Axi-symmetric finite element model

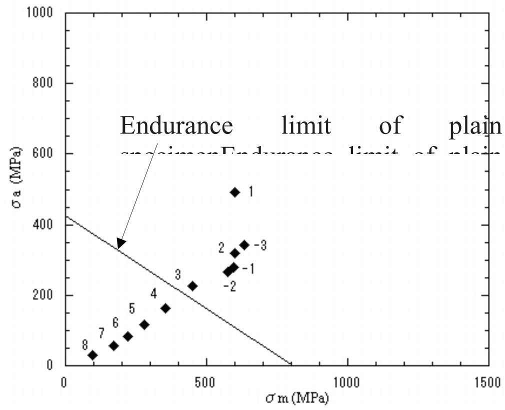

Fig. 12 Endurance limit diagram (α=0 μm, σ_a=100 MPa)

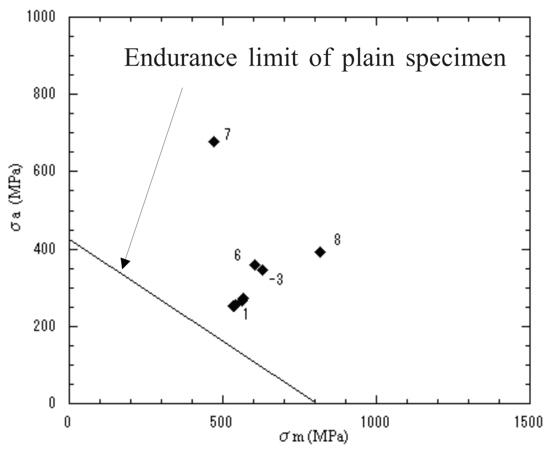

Fig. 13 Endurance limit diagram (α=15 μm, σ_a= 100 MPa)

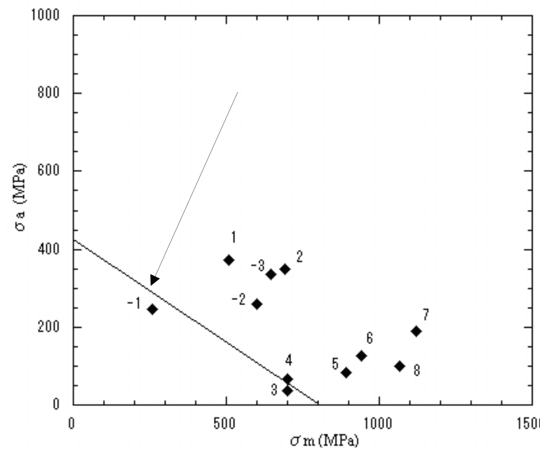

Fig. 14 Endurance limit diagram (α= 33μm, σ_a=100 MPa)

From Fig.12 we can see that for the normal bolt and nut, the No.1 thread bottom has the highest stress amplitude, which corresponds to the fracture position in the fatigue experiment as shown in the section 3. In Fig. 13, when a pitch difference of α=15μm is introduced, the stress amplitude decreases at the No.1 thread bottom. On the other hand, the stress amplitude at No.6, No.7 and No.8 increases significantly. For α=33μm, the severe stress status occurs nearby No.1 thread and No.7 thread as shown in Fig.14.

6 CONCLUSIONS

In this study, a slight pitch difference is designed between bolt and nut. The fatigue experiment have been performed, and the effect of pitch difference on the stress status of the bolt thread bottom has been numerically analyzed by using the finite element method. The conclusions can be summarized as follows:

1) It is found that α=15μm is the most desirable pitch difference to extend the fatigue life of the bolt and nut. Compared with the normal bolt and nut, the fatigue life for α=15μm can be extended by about 1.5 times.
2) It is found that the stress amplitude at the No.1 thread bottom decreases significantly when the pitch difference is introduced. For α=15μm, the FEM analysis result shows that high stress

amplitude occurs at No.6, No.7 and No.8 thread bottom, which almost corresponds to the experimental observation.

3) For the specimens α=15μm, the fatigue life improvement mechanism is considered. It is found that the crack occurs at No.5 thread in the first place, then it extends toward No.1 thread and finally fracture happens nearby No.1 thread. Therefore, the fatigue life of the bolt is extended compared with the normal bolt and nut.

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