Experimental and numerical studies of bolted joints subjected to axial excitation

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Abstract. The dynamic behavior of bolted joints subjected to axial excitation is investigated using experimental and numerical methods. Firstly, the amount of reduction in clamp force is found by experiments. In addition, the damage of threads is analysed using Scanning Electron Microscope (SEM) and Energy Dispersive X-ray (EDX). The effects of the excitation level, the tightening torque and the lubrication (MoS_2) of bolt threads on the clamp force loss and the damage of threads are studied. Finally, the amplitude of micro slip in the radial direction along the specified path is studied using finite element method (FEM). In addition, the hysteresis loop of the axial load versus the relative displacement of the joint is also investigated and reproduced by the Masing model.

Introduction

Bolted joints have found wide-spread use in many machines and structures. As basic fastening pieces, they have direct influences on the safety and reliability of a structural system. Most of past studies are focused on the energy dissipation and the damping of bolted joints [1, 2], parameter uncertainties [3], failure and fatigue of structural joints [4], and loosening mechanisms. Goodier et al. [5] seem to have been the first to study the loosening mechanism for a bolt under axial load. They pointed out that an increase in load caused a bolt thread to move radially inward and a nut thread radially outward. Experiments and analyses by Hess et al. [6] with thread fasteners loaded by gravity and subjected to axial harmonic vibration revealed that thread components can twist with or against gravity in the presence of vibration. Nassar et al. [7] investigated the permanent loss of clamp force after the removal of a separating force from a joint in which the fastener preload slightly exceeded its proportional limit.

In this paper, experimental method is used for investigating the dynamic behavior of bolted joints, made of aluminum alloy and equipped with thread insert, subjected to axial excitation. The clamp force loss and the damage of threads are studied. Moreover, the radial micro slip between the contact threads is analysed using the finite element method. The hysteresis loop is reproduced by using the Masing model and is found to be in good agreement with that from the detailed FE model.

Experimental method

A joint tested in the experimental investigation is shown in Fig. 1. Two bolt testing fixtures made of high strength steel are clamped with a bolt and a nut. One fixture is fixed at one end and an axial excitation is applied at the end of the other fixture. Electro zinc plated (EZP) bolts are tested in the experiments. The square nuts are made of aluminum alloy and equipped with thread insert. Between the bolt testing fixture and the nut, a load cell is used to measure the clamp force. In order to protect the load cell from fretting wear, a thin washer made of aluminum alloy is placed in between the load cell and the bolt testing fixture. In the experiments, five levels of tightening torque, M_0, are used. They are 30 N·m, 35 N·m, 40 N·m, 45 N·m, and 50 N·m. The axial excitation, denoted as F_e, is the controlling parameter. The amplitude of the axial excitation, F_e, will be referred to as $A_F/2$. A number of $A_F/2$ values are used and they range from 7.5 kN to 12.25kN.

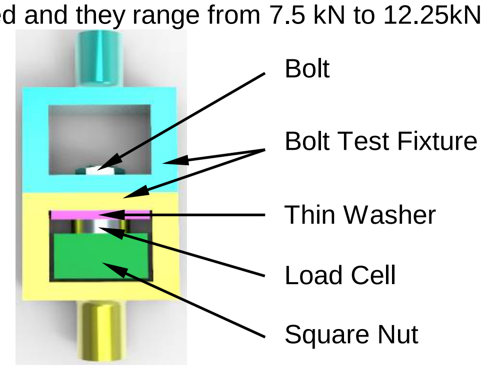

Fig. 1 Experimental setup

Results and discussion

The SEM morphology and EDX patterns are shown in Fig. 2. As can be seen from the graph, the damage is non-uniform. Due to the effect of fatigue wear, the damage surface shows delamination phenomenon in the area denoted as I. EDX pattern of point A shows electro zinc plated (EZP) coating of the bolt has been completely removed. Therefore, the main mechanism is delamination in this area. In the II area, ploughing with obvious plastic flow is the main wear phenomenon. The EDX analyses of wear scars show that point C has a higher O-element peak than that of point B. Therefore, the main mechanisms are abrasive wear, adhesive wear and oxidative wear in this area.

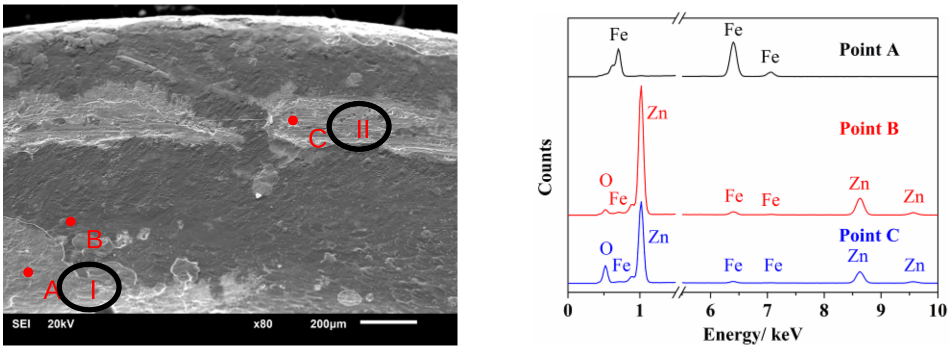

Fig. 2 SEM morphology and EDX patterns corresponding to wear scar of the first thread surface (M_0=30 N·m, A_F/2=10 kN, N=10^6 cycles)

After N loading cycles, function R_F (N) is defined as the percentage of clamp force to preload, and function R_T (N) is defined as the percentage of the breakaway torque necessary to loosen the tightening torque. The self-loosening curves for five levels of the tightening torque are shown in Fig. 3. With increasing tightening torque, the amount of reduction in clamp force decreases and the damage is reduced gradually as shown by the SEM morphologies. As shown in Fig.4, when the tightening torque is 30 N·m, R_T (10^6) is larger than 90%, but R_T (10^6) is smaller than 70%. Consequently, it is not very suitable to use torque wrenches to monitor whether bolted joints are loose.

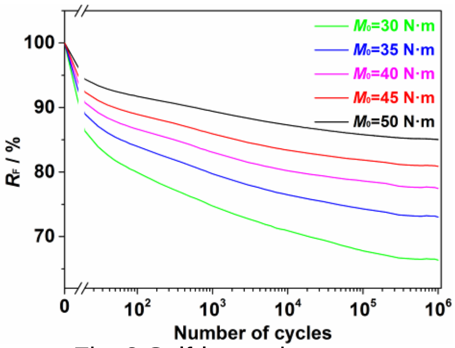

Fig. 3 Self-loosening curves for varying tightening torques

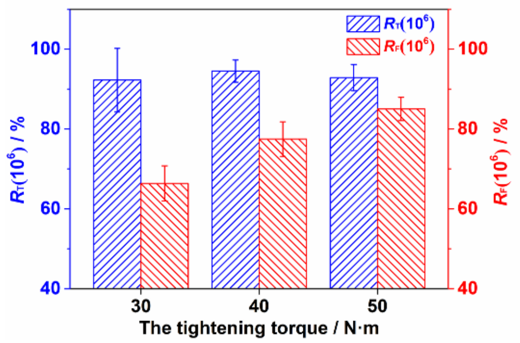

Fig. 4 Self-loosening curves for varying tightening

Similarly, for varying amplitudes of the axial excitation and the MoS_2-lubricated bolt, the clamp force loss and the damage of threads are studied. Finite element method is used for investigating the amplitude of micro slip in the radial direction along the specified path. Moreover, the hysteresis loop is reproduced by using the Masing model and is found to be in good agreement with that from the detailed FE model.

Conclusions

1. The clamp force drops rapidly at the beginning of the experiment, and then reduces gradually. The wear mechanism of the contact surface between threads is complicated. It contains all of four basic wear mechanisms, namely, abrasive wear, adhesive wear, oxidative wear and delamination.
2. With the tightening torque increasing and the amplitudes of the axial excitation decreasing, the damage of threads is reduced gradually, and the amount of reduction in clamp force decreases. Due to lubrication of bolt threads, the degree of loosening decreases and the damage of threads gets slight for lubricated bolts.
3. The hysteresis loops of the bolted joint can be well reproduced by using a fourth order Masing model.

References

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