Optimal design of assembly interface for high contact performance

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High contact performances of crucial assembly interfaces are desired for guaranteeing the static and dynamic performances of the equipment or machines. The uniformity of the contact stress distribution is measure to the contact performance. Aiming at improving the distributing uniformity of contact stress, interface shape design and material stiffness design around the assembly interface are conducted. Gradient-free optimization method is proposed and the effectiveness of the proposed methods is validated through several design cases. For the gradient-free material stiffness optimization method, the influence of friction behavior on the optimization result is further investigated.

Keywords: Contact stress, distributing uniformity, interface shape, material stiffness, friction behavior

1. Introduction

High contact performances are desired for crucial assembly interfaces in equipment or machines in engineering practice. The uniformity of the contact stresses is measure to the contact performance. Traditional methods, such as optimizing the layout of the fasteners and the assembly process, have limited effects on improving the uniformity of the contact stress. The interface shape and the material stiffness, as two factors strongly influencing the contact stress distribution [1-4], are often ignored during the existing engineering design. This study aims to develop interface shape and material stiffness optimization methods for improving the distributing uniformity of contact stress.

2. Methods

For the interface shape and the material stiffness optimization, the gap distance and Young's modulus are treated as the design variables respectively, while objective functions are both the variance of contact stress.

2.1. Basic equation

For interface shape optimization:

$$\varepsilon_i = M \times \frac{\sigma_i}{\sigma_{\max}} \tag{1}$$

$$M^{k+1} = \begin{cases} C_1 \cdot M^k & \text{if } \delta^k < \delta^{k-1} \text{ and } \delta^{k-1} < \delta^{k-2} \\ C_2 \cdot M^k & \text{if } \delta^k > \delta^{k-1} \end{cases}$$

For material stiffness optimization:

$$E^{k+1}(w_t) = E^k(w_t) \times STI \times \frac{\sigma^k_{mean}}{\sigma^k(w_t)} \tag{2}$$

$$E^{k+1}(\omega_t) = \begin{cases} E_{\min} & \text{if } E^{k+1}(\omega_t) \le E_{\min} \\ E^{k+1}(\omega_t) & \text{if } E_{\min} < E^{k+1}(\omega_t) < E_{\max} \\ E_{\max} & \text{if } E^{k+1}(\omega_t) \ge E_{\max} \end{cases}$$

2.2. Design case

One of the design cases is the single bolted joint model as shown in figure 1.

2.3. Results

After the interface shape optimization or the material stiffness optimization, the uniformity of the contact stress is improved significantly, as shown in figure 2.

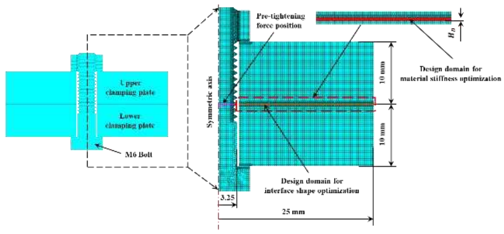

Figure 1: A single bolted joint model.

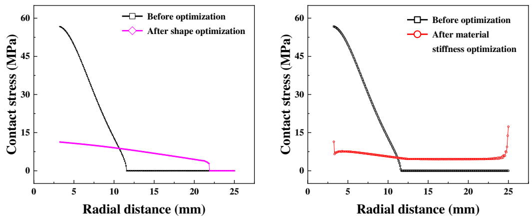

Figure 2: Contact stress distributions before and after interface shape optimization (left) and material stiffness optimization (right).

3. Discussion

Gradient-free optimization method is proposed to carefully design the interface shape and material stiffness, and both the interface shape design and material stiffness design are proved to be effective on homogenizing the contact stress field. Additionally, the effective contact area is enlarged significantly. For the material stiffness optimization method, the numerical results indicate that the influence of the friction behavior on the optimization result is problem-dependent.

4. References

[1] Lin Qiyin, et al., "An Optimization Design of Contact Interface Material Stiffness for Improving the Uniformity of the Contact Pressure," ASME Journal of Tribology, 2020, 142,6,1-18.

[2] Zhou Yicong, et al., "Bidirectional evolutionary optimization design of material stiffness for the uniformity of the contact stress," European Journal of Mechanics a-Solids, 2021, 89: 104288.

[3] Zhou Yicong, et al., "Material stiffness optimization for contact stress distribution in frictional elastic contact problems with multiple load cases," International Journal of Mechanics and Materials in Design, 2021, 17, 3, 503-519.

[4] Zhou Yicong, et al., "Combined interface shape and material stiffness optimization for uniform distribution of contact stress," Mechanics Based Design of Structures and Machines, 2020.