Analytical Modeling of Clearance-Fit Pinned Joints with Functionally Graded Interlayers

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Loaded pinned joints are a classical non-axisymmetric contact mechanics problem and remain one of the most common solutions for connecting articulated mechanical components. Typically, a stiff cylindrical pin interacts with a surrounding material of lower stiffness. Because a small clearance is needed to allow rotation, contact is limited to only part of the hole surface, with an extent that is unknown a priori and increases nonlinearly with the applied load. Excessive clearance can also promote wear, fatigue, and eventual failure. For these reasons, the problem generally requires advanced analytical or numerical treatment. The work [1] provided an analytical solution for the frictionless clearance-fit contact problem between a rigid circular pin and a circular FGM lug with power-law grading, showing that load-bearing capacity can be improved by increasing both the elastic modulus and strength of the FGM near the contact surface. The present work investigates the plane problem of a rigid loaded pin in advancing contact with an FGM ring inserted around a hole in an infinite isotropic elastic plane under clearance-fit conditions. The shear modulus of the FGM ring varies radially according to a power law and tends to that of the surrounding elastic plane, while Poisson's ratio is assumed constant and identical in both materials. Using the general polar-coordinate expressions for stresses and displacements [2], the frictionless contact problem is reduced to a system of dual trigonometric series, from which an infinite linear system for the Michell-type coefficients is obtained and solved by truncation. To address the nonlinearity of the advancing contact problem, an inverse solution strategy is adopted: the contact pressure is first determined for assigned contact angles, and the corresponding pin load is then computed, yielding a nonlinear relationship between contact angle and load. The results show that, by properly tailoring the material gradation across the ring thickness, the contact angle can be increased, leading to more uniform contact pressure and hoop stress distributions and thus reducing the risk of failure in fasteners and bolted connections. The analytical solution is verified through the invariance of an M-integral-based quantity along circular contours around the hole and further validated against finite element results, showing excellent agreement. Overall, the study provides practical guidance for improving the load-bearing capacity of pinned joints using FGMs and opens new perspectives for the optimized design of cylindrical connections.

References

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